# MATERIAL CHARACTERIZATION OF VEIN ADAPTATION IN PRESSURE AND FLOW-OVERLOAD

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## Introduction

Sustained alterations in pressure and flow elicit dimensional (thickness and radius) and mechanical (stiffness) alterations in the artery wall, serving to maintain shear and wall stresses to homeostatic levels, but our knowledge of hemodynamically-driven vein adaptation is limited and less consistent [Humphrey, 2002]. The present study aimed to characterize our prior inflation/extension vein data from a porcine model of arteriovenous fistula used for hemodialysis [Kritharis, 2011] with a structure-based strain-energy function (SEF).

## Methods

The internal jugular vein from six healthy male Landrace pigs (65–70 kg) was subjected to pressure and flow-overload, by connecting it via an e-PTFE graft with the carotid artery. Both the anastomosed and contralateral (control) veins were removed four weeks later and submitted to inflation/extension testing. Our choice for a material model was:

$$W = b_{\theta\theta}E_\theta^2 + b_{zz}E_z^2 + b_{\theta z}E_\theta E_z + \\ + \sum k_1^m \big/ 4k_2^m \{\exp[k_2^m((\lambda^m)^2 - 1)^2] - 1\} \quad (1)$$

where model parameters $b_{\theta\theta}$, $b_{zz}$, $b_{\theta z}$, and $k_1^m$ were with stress units and $k_2^m$ were unit-less, $\lambda^m = \sqrt{\mathbf{n}^m\mathbf{C}\mathbf{n}^m}$ was the stretch of the $m^{\text{th}}$-fiber family, whose unit vector in the zero-stress state was inclined to the longitudinal axis with angle $a^m$, and $E_i = 1/2(\lambda_i^2\text{-}1)$, $i=\theta,z$ were principal Green strain components. Superscripts *m*=*c*, *a*, *d* denoted the circumferential, axial, and diagonal-fiber families. Model parameters were optimized with the Nelder-Mead algorithm.

## Results

The curves of anastomosed veins were displaced to greater radii than control veins and their axial force range was wider (Figure 1). Anastomosed veins exhibited lower stiffness than control at low pressures and low-stress stiffness parameters $b_{\theta\theta}$, $b_{zz}$, and $b_{\theta z}$ were smaller on average (Table 1). At higher pressures, the curves of anastomosed veins displayed a steeper slope and parameters $k_1^a$ and $k_1^d$, reflecting high-stress stiffness, received higher values than control.

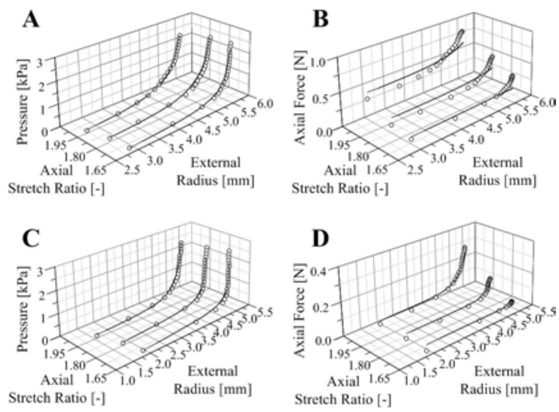


*Figure 1: 3D scatter plot of pressure and axial force vs. external radius and axial stretch data (open symbols), with the fits by Eq. (1) (solid lines) for a representative anastomosed (A,B) and control vein (C,D).*

| $b_{\theta\theta}$ | $b_{zz}$ | $b_{\theta z}$ | $k_1^c$ | $k_2^c$ | $k_1^a$ | $k_2^a$ | $k_1^d$ | $k_2^d$ | $a$ | $\varepsilon$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.1± 0.1# | 0.2± 0.1# | 0.0± 0.0# | 0.9± 0.2 | 1.3± 0.6 | 3.7± 0.9# | 0.2± 0.1 | 2.4± 0.8# | 3.1± 0.8 | 58± 3# | 0.18± 0.03 |
| 2.6± 0.9 | 4.0± 0.9 | 2.6± 0.6 | 1.2± 0.5 | 1.0± 0.2 | 1.1± 0.1 | 0.2± 0.1 | 0.2± 0.1 | 2.5± 0.6 | 47± 3 | 0.18± 0.02 |

*Table 1: SEF parameters and root-mean-square-error ε. #=p<0.05 (t-test), anastomosed (upper) vs. control (lower row) a =orientation angle of diagonal families.*

## Discussion

The quadratic and four-fiber family SEF described realistically our testing data. The SEF parameters computed implied that anastomosed veins were stiffer and less compliant at high pressures than control veins. The present data may advance our appreciation of vein mechanical adaptation under pressure and flow-overload conditions.

## References

Humphrey J.D., Cardiovascular Solid Mechanics: Cells, Tissues, and Organs, Springer, New York, 2002.

Kritharis E. *et al*, Biorheology, 47:297-319, 2010.