

Biaxial Mechanical Properties of Venous Valve Leaflet Tissues

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Introduction: Venous valve incompetence is a major cause of the chronic venous insufficiency (CVI). When the venous valves become incompetent, blood reflux can occur, which results in blood pooling in the lower extremities and therefore causes CVI. To date, only uniaxial tensile studies have been reported on venous valve leaflet tissue mechanical properties. However, it was inadequate to describe the complex mechanical behaviors of venous valve leaflets, whose native mechanical loading state is intrinsically multi-axial. In our study, we conducted equibiaxial tensile tests and collagen assay on bovine jugular and saphenous vein valve leaflet tissues to better understand their biaxial nonlinear and anisotropic mechanical properties and quantitatively analyze their collagen concentration.

Materials and Methods: Bovine jugular and saphenous venous valves were used in lieu of human tissues due to their relatively large size, ease to access, and the previous usage in prosthetic studies. The jugular venous valves (JV) had the dimension of 25~30mm in the circumferential direction, with 8~15mm in the radial direction. The saphenous venous valves (SV) had the dimension of 10~15mm in the circumferential direction and 3~5mm in the radial direction. The leaflets were collected from the veins and put into biaxial mechanical testing and collagen assay. The central belly region of each leaflet specimen was isolated and mounted onto the BioTester. The specimens were stretched equibiaxially in both circumferential and radial directions to 60% strain at the rate of 1%/s under displacement control. Corresponding displacement and force data were recorded through the load cells. After mechanical testing, the specimens were then frozen in preparation for collagen assay. The specimens were weighed and put into collagen extraction solution for 120h. Then the collagen concentration of each sample was obtained by adding dye reagent and analyzing the 550nm light absorbance of each sample.

Results and Discussion: Bovine jugular valves had non-linear anisotropic mechanical properties (Fig. 1). Tangent moduli of elasticity in the circumferential direction were larger than those in the radial direction for all the samples ($p < 0.05$), which indicated the venous valves were stiffer in the circumferential direction than in the radial direction (Table 1). For JV tissues, specimens from different locations of the vein were separated into three groups, as the Proximal, which was closer to the heart, the Middle, and the Distal. For SV tissues, the specimens were separated into the Proximal and the Distal groups. By comparing the leaflet properties from different locations, we observed that all JV and SV Distal tissues showed anisotropic mechanical properties, while SV Proximal tissues showed isotropic properties. Moreover, the JV tissues showed an increasing trend in collagen concentration from the Proximal to the Distal groups, while the SV tissues showed a decreasing trend (Fig. 2). The difference among the leaflets from different locations indicated that inter-valvular variabilities existed among the venous valve leaflet tissues. As the blood return to the heart from the distal end to the proximal end, leaflets from different locations are exposed to different pressure levels, which might have caused such inter-valvular variability. By comparing the properties of the leaflets from the same valve location, we observed that they did not possess the same properties. One of the leaflet appeared to have stronger mechanical properties than the other one, which indicated that intra-valvular variability existed among the leaflet tissues.

Conclusions: All of the jugular valve leaflet and distal saphenous valve tissues possessed anisotropic non-linear mechanical properties. The leaflets appeared to be stiffer in the circumferential direction than in the radial direction. Proximal valves from the saphenous veins possessed isotropic mechanical properties. The collagen concentration of the tissues showed an increasing trend from the proximal end to the distal end in jugular veins, while the opposite in saphenous veins. The difference in blood pressure levels might have caused such variabilities. To the best of the author’s knowledge, this is the first study reporting the biaxial mechanical properties of venous valve leaflet tissues and thus contributes toward refining our collective understanding of valvular tissue biomechanics.

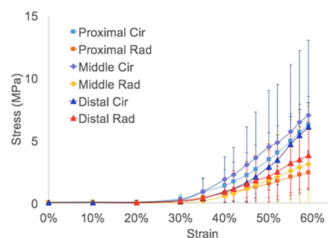


Figure 1: JV stress-strain curves

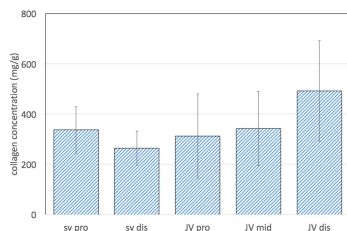


Figure 2: Collagen concentration

| | JV Proximal | | JV Middle | | JV Distal | |
|-------------------------------------|-------------|--------|-----------|--------|-----------|-------|
| | Cir | Rad | Cir | Rad | Cir | Rad |
| Tangent modulus of elasticity (MPa) | 26.98 | 8.89 | 23.49 | 10.35 | 29.72 | 15.42 |
| | ±9.36 | ±5.57 | ±20.21 | ±16.26 | ±6.18 | ±9.46 |
| | SV Proximal | | SV Distal | | | |
| | Cir | Rad | Cir | Rad | | |
| Tangent modulus of elasticity (MPa) | 62.66 | 41.61 | 92.08 | 31.76 | | |
| | ±34.88 | ±16.01 | ±27.86 | ±13.87 | | |

Table 1: Tangent moduli of elasticity of tissue

Acknowledgements: This research was supported by NSF CAREER GARDE 1553430.