Structure-function characterization of fresh human heart valves

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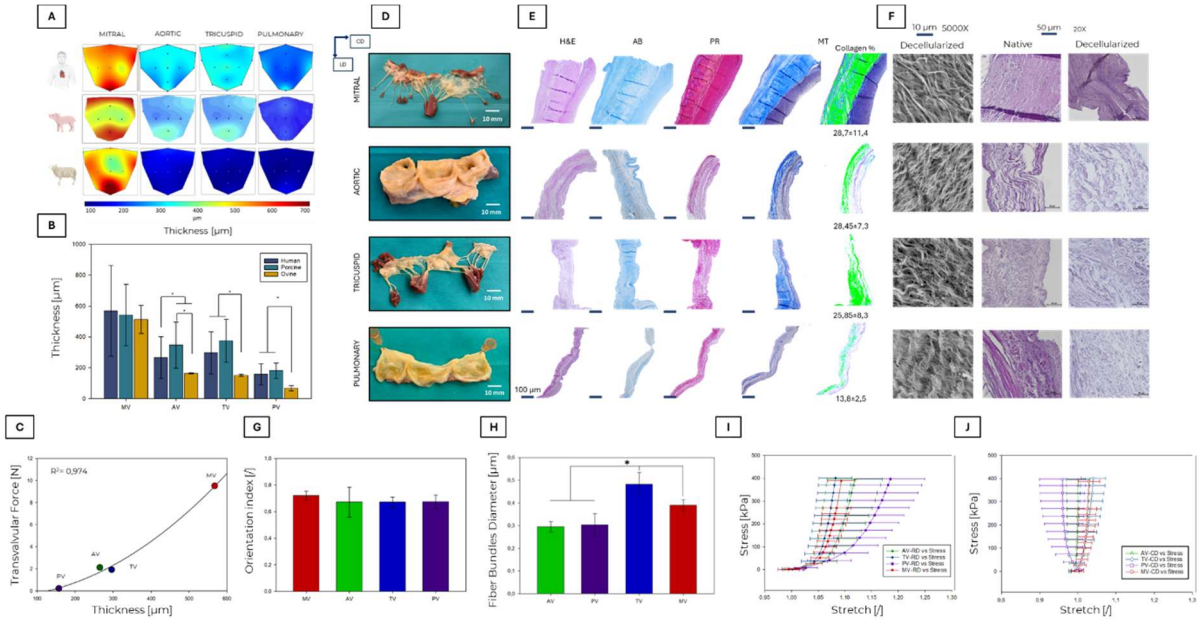

Figure 1.

A-B. Comparative analysis of human, porcine, and ovine valve thickness distribution over the leaflet area for mitral, tricuspid, aortic, and pulmonary valves. All four valves had greater thickness in the coaptation and free edge regions

C. Human heart valve thickness VS transvalvular Force. Thickness topologies correlate with the transvalvular force values reported in the literature for the AV, MV, PV, and TV.

D. Human heart valve gross examination. The four dissected human heart valves including chordal apparatus for MV and TV.

E. Human heart valve histological analysis. Hematoxylin and Eosin (H&E) Alcian Blue (AB), Picrosirius Red (PR) and Masson's trichrome (MT) staining were performed to characterize cellular and structural constituents. Collagen quantity in leaflet cross-sections was estimated by digital image processing.

F. Surface analysis. Decellularized human heart valve leaflets were analyzed using scanning electron microscopy (SEM). Histological analysis confirmed successful cell removal.

G-H. Fiber orientation and fiber bundles diameter in human heart valves. The orientation index (OI D'Amore et al. Biomaterials 2010) confirms the anisotropic structure of the valves (OI>0.5), with level of fiber alignment among the valves not statistically different. Consistently with our previous study on porcine and ovine tissue, human MT and TV had larger fiber bundle diameters than AV and PV.

I-J. Native human valve biaxial mechanics. Stress-strain curves for each valve leaflet were generated using the equi-stress protocol in both the circumferential and radial directions**.** When compared to the semilunar valves, the atrioventricular valves exhibited greater stiffness along the radial direction. The atrioventricular HVs mechanical response is reflective of the different coaptation mechanism which is driven by the action of the chordae tendineae. In contrast, outflow tract valves rely on the sinus shape and greater leaflet anisotropy to properly close and prevent backflow.

ABSTRACT (300 words)

OBJECTIVES

The four human heart valves (HVs) exhibit differences in their physiology which are reflected in their structural and mechanical properties. HVs physiological properties still remain poorly characterized and are largely neglected in the design of commercially available prosthetic devices, with data being extracted only from animal or cadaveric tissues. This study aims to fully characterize human HVs structure and mechanics at the organ and tissue scale.

METHODS

Human valve samples from heart transplant patients were tested within 24 hours from the explant procedure. Thickness was measured across the whole leaflet area for the aortic, mitral, pulmonary, and tricuspid valves (AV, MV, PV, TV). Leaflet cellular and structural constituents were characterized using histological staining a decellularization protocol allowed for fiber network analysis via electron microscopy. Collagen fiber angle distribution and bundle diameter were quantified with digital image processing. Biaxial mechanics was measured on belly region samples utilizing a Lagrangian equi-stress control protocol with 400kPa peak stress.

RESULTS

Results showed that HVs collagen quantity and thickness correlates with transvalvular pressure, with increased thickness values measured at coaptation and free edge regions. The MV exhibited a higher average thickness. MV and TV showed greater stiffness than the semilunar valves (AV, PV), along the radial direction.

CONCLUSIONS

This study highlights structural and functional differences in fresh human HVs. Establishing a detailed HV structural-function database remains critical to assist valve engineering, and implement biomimicry in leaflet, supra and sub-valvular apparatus design.