Impact of Venous Hemodynamics on Development of Endovascular Stent Vein Valves

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Purpose

The purpose of this study was to describe the hemodynamics of venous blood flow across deep vein valve stations in normal, refluxive, surgically corrected, valve-stented and stent supported vein valve transplanted veins and how biomechanical factors impact on stent-vein valve design.

Material and Methods

Using computational fluid dynamics using zero dimensional, lumped-parameter network models combined with three-dimensional finite element meshed models of sheep internal jugular vein, the blood flow across the valve station was mapped in experimental (a) normal, (b) refluxive, (c) surgically corrected vein valve (trapdoor valvuloplasty), (d) valve-stented (externally nitinol supported valve stations), and (e) stent-supported valve transplanted (vein valve segment with outer nitinol stents at ends) veins. Flow rates (antegrade and refluxed), shear stress distribution and changes in geometric and fluid dynamics parameters (eg, velocities, stagnation, and boundary layering effects) were recorded, analyzed and compared between the five groups using non-linear (FEA) and CAD, motion and structural (Maya) software and valve leaflet integrity was assessed by histopathologic examination at 6 months post implantation.

Results

Normal valves show four phases of the valve cycle that represent the "forward-flow loop" propulsion. Incompetent valves have loss of valve equilibrium or "holding" phase before the valves attempt to close, leading to reflux. Their cusps and vein walls below the valve station also have areas of low shear that may predispose to thrombosis and inability for antegrade propulsion. These areas were seen to develop excessive thickening of vein wall adjacent to the valve station with valve stiffening. Surgically corrected refluxive valves behave hemodynamically like normal valves but have stagnation and secondary vortical turbulence loops that increase the propensity for eventual valve station dilatation and reflux. Valve-stented veins show loss of complete valvular opening phase resulting in altered geometry and boundary layering at the valve stent level resulting in severe pressure differential possibly leading to microfractures of valve leaflets observed. Stent-supported vein wall transplants closely modeled along normal flow hemodynamics with least stagnation, boundary effects, valve immobility, vein wall thickening, and valve leaflet fractures. Low shear areas were transferred to pre-stent locations and didn't affect vein valve leaflet function.

Conclusions

Development of vein valve stents is in its infancy. Lessons learned from our study are in favor of stent supported vein valve transplantation. Further research is needed to clarify the future role of endovascular valves in the treatment of deep venous valvular insufficiency.