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Computational Modeling of Human Bicuspid Pulmonary Valve Dynamic Deformation in Patients with Tetralogy of Fallot

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Abstract: Pulmonary valve stenosis (PVS) is one common right ventricular outflow tract obstruction problem in patients with tetralogy of Fallot (TOF). Congenital bicuspid pulmonary valve (BPV) is a condition of valvular stenosis, and the occurrence of congenital BPV is often associated with TOF. Dynamic computational models of normal pulmonary root (PR) with tri-leaflet and PR with BPV in patients with TOF were developed to investigate the effect of geometric structure of BPV on valve stress and strain distributions. The pulmonary root geometry included valvular leaflets, sinuses, interleaflet triangles and annulus. Mechanical properties of pulmonary valve leaflet were obtained from biaxial testing of human PV leaflet, and characterized by an anisotropic Mooney-Rivlin model. The complete cardiac cycle was simulated to observe valve leaflet dynamic stress/strain behaviors. Our results indicated that stress/strain distribution patterns of normal tri-leaflet pulmonary valve (TPV) and the BPV were different on valve leaflets when the valve was fully open, but they were similar when valves were completely closed. When the valve was fully open, the BPV maximum stress value on the leaflets was 197.2 kPa, which was 94.3% higher than of the normal TPV value (101.5 kPa). During the valve was fully open, the stress distribution in the interleaflet triangles region of the PR was asymmetric in the BPV model compared with that in the TPV model. The geometric orifice area value in the completely opened position of BPV model was reduced 55.6 % from that of the normal PV. Our initial results demonstrated that valve geometrical variations with BPV may be a potential risk factor linked to occurrence of PVS in patients with TOF. Computational models could be a useful tool in identifying possible linkage between valve disease development and biomechanical factors. Large-scale clinical studies are needed to validate these preliminary findings.

Keywords: Heart model; pulmonary valve; bicuspid pulmonary valve; tetralogy of Fallot

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