Different patterns of pulmonary venous flow in myocardial hypertrophy: hypertrophic cardiomyopathy versus athlete's heart

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This report summarizes the results of two studies by our group in which pulmonary venous flow during reduction of venous return to the heart was investigated in hypertrophic cardiomyopathy (HCM)[1] and athletes[2], i.e. in two conditions in which the left ventricular (LV) diastolic properties, namely LV relaxation, vary in a divergent direction from normal. Sixty-degree head-up tilting and the standing position were utilized in HCM and athletes, respectively, for reducing venous return.

The HCM group consisted of 21 newly diagnosed men (mean age 46 ± 6 years). All had regular sinus rhythm, and no signs of intraventricular obstruction and normal LV ejection fraction at rest. The maximal LV wall thickness from any location was determined and diagnosis of HCM was considered[3] when maximal LV wall thickness by two-dimensional echocardiography was ≥ 15 mm. In these patients maximal wall thickness averaged 17.3 ± 1.2 mm. Patients with a spade-shaped LV cavity were not included. Controls (22 males, mean age 44 ± 8 years) were free from cardiovascular or lung diseases, showed a normal echocardiogram, and were not professional sportsmen. This group had an average maximal LV wall thickness of 9.1 ± 1.1 mm.

The athlete group included 11 female subjects (mean age ≈ 25 ± 0.6 years), who were involved in regular aerobic training programs and engaged in competitive long-distance running events. None were taking any pharmacological agent. In them, LV mass was calculated according to the American Society of Echocardiography recommendations[4], and averaged 92 ± 8 g/m^2. Control subjects (mean age ≈ 25 ± 0.8 years) were free from cardiovascular or lung diseases, had an average LV mass of 75 ± 13 g/m^2, were active in daily life, and did not participate in regular aerobic training programs.

The athletes and controls performed exercise tests on a treadmill and were encouraged to exercise to volitional fatigue. Tests were terminated on the subject's verbal request, and maximal exercise tolerance time was determined.

HCM patients and controls were head-up tilted with a motorized cantilevered table. Pulmonary venous flow records were taken after an initial rest of at least 15 min in the horizontal position, after 10 min tilting at 60° angles. In athletes and controls, records were taken in the supine position after an initial rest of at least 15 min; after supine measurements were made, subjects assumed an upright position until heart rate was stable and another set of recordings was made. Pulmonary venous flow velocity was examined with a 2.5 MHz Doppler imaging transducer placed at the cardiac apex and was obtained by placing the sample volume 0.5 to 1.0 cm into the upper right pulmonary vein. We determined (with a computer-integrated digitizing pad and specifically designed software) peak forward velocities during systole (X) and diastole (Y), Y deceleration time and flow velocity integrals of systolic (Xi) and diastolic (Yi) forward flow waves. The systolic filling fraction of pulmonary venous forward flow was the ratio of the systolic to the sum of the systolic and diastolic velocity integrals.

In the flat position, HCM patients, compared to controls, showed a greater X/Y ratio, due to a raised X wave velocity and a diminished peak Y wave velocity. The time velocity integral of the Y wave was also lower and the time-velocity integral and percent total flow velocity integrals of the X wave were greater than normal. In controls, during head-up tilting, as compared to the flat position, the peak velocity and time-velocity integral of the X wave became reduced and those of the Y wave became augmented, resulting in a diminished peak X/Y velocity ratio. In patients, supine differences from normal persisted at 60° head-up tilting. With the displacement there was no effect on the X wave peak velocity and time-velocity integral, a reduction of the peak velocity and time-velocity integral of the Y wave and an increase of the X/Y ratio.

Supine Doppler variables did not show any differences between controls and athletes.

Compared to the supine position, both groups showed greater Y wave peak velocity and time-velocity integral, and lower X wave peak velocity, time-velocity integral, Xi/Yi ratio, and systolic filling fraction while standing. The upright values for X wave peak velocity and time-velocity integral, X/Y peak velocity, and Xi/Yi ratio and systolic filling fraction of X wave were significantly lower, and the time-velocity integral of the Y wave was significantly higher in athletes compared to controls. Percent variations from supine of each of these variables in female athletes significantly exceeded those in controls. In some instances (Xi, Yi, Xi/Yi) these changes were twice as great as in athletes. Peak exercise tolerance time averaged 751 ± 20 s in female controls and 1035 ± 88 s in female athletes ($p < 0.01$).

A lower X/Y velocity integral ratio in the upright position was a multivariate independent predictor of a greater exercise performance.

Comments

In normal subjects, a diminished venous return with head-up tilting or with standing reduces the right ventricular volume[1,5] and, through the ventricular interaction, moves the pressure-volume relationship in the left ventricle from being predominantly mediated through the pericardium (horizontal position) to being mediated by myocardial properties[6,7]. This, likely, results in a facilitated movement of blood from the atrium to the ventricle, and in a lowered downstream pressure for pulmonary venous return, which moves mainly to the phase of ventricular diastole (predominance of the Y wave), during which the atrium functions as an open conduit. In the presence of impaired diastolic function, as occurring in HCM, a joint involvement of the systolic and diastolic properties of the left atrium appears to be essential in assisting the left ventricle to adapt to reduced venous return.

In our patients the forward systolic pulmonary venous flow was dominant during head-up tilting. Notably, factors that determine the pulmonary venous flow during systole include left atrial pressure, left atrial compliance and relaxation. Consistent with these interpretations, tilting was associated with an increase in the X/Y ratio, which was reduced by the same degree of tilting in healthy subjects. Thus, the heart in HCM adapts to diminished venous return by cardiac mechanisms (diastolic and systolic function of the left atrium) that are basically different from those of a normal heart (ventricular interaction, diastolic LV properties).

Findings in female athletes suggest that training causes variations in LV diastolic properties that may not be detected in the supine position[2]. The effects of exercise conditioning can be unmasked by performing an analysis of the pulmonary venous flow in the upright position. These effects are reflected by an enhanced movement compared to controls of the pulmonary venous flow to the phase of ventricular diastole, suggesting that training may influence ventricular relaxation and viscoelastic forces of the myocardium, which probably shifts the pressure-volume relationship to a more favorable curve.

The question has repeatedly been addressed as to whether improvement of diastolic filling at rest may contribute to the increased exercise maximal performance with training[8,9]. We attempted to focus on the influence of the pulmonary venous flow pattern, observed under the challenge of an orthostatic stress, on exercise capacity. The pulmonary venous return pattern in the upright position was the best correlate in multivariate analysis with the maximal exercise tolerance time, suggesting that improvement in diastolic function with training, even when it is undetected in the supine position, may contribute to exercise capacity.

As a general consideration, the analysis of the pulmonary venous flow under the challenge of reduction in preload, appears to be a very useful tool for investigating diastole, and for revealing alterations that are undetected with the simple analysis of the transmitral flow and in the supine position. These can be used as baseline information for future studies.

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