2. Noninvasive assessment of left ventricular systolic and diastolic function using Doppler mitral regurgitant velocity profile

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Introduction

Maximal positive $dp/dt$ and maximal negative $dp/dt$ of left ventricular pressure are important parameters for assessing left ventricular systolic (maximal positive $dp/dt$) and diastolic (maximal negative $dp/dt$) function [1]. However, these parameters require high fidelity pressure recordings with the accompanying risk of an invasive procedure. A noninvasive method for assessment of maximal $dp/dt$ and maximal negative $dp/dt$ would, therefore, be of great value.

Mitral regurgitation is commonly found in patients with a variety of cardiac conditions, especially in congestive heart failure [2, 3]. Continuous-wave Doppler echocardiography is able to record the complete regurgitant velocity profile during entire systole (isovolumic contraction and ejection period) and isovolumic diastole before left atrial and ventricular pressures cross over and the mitral valve opens [4, 5]. Using the simplified Bernoulli equation the continuous-wave Doppler mitral regurgitant velocity curve can be converted to an atrioventricular pressure gradient curve [5, 6]. The instantaneous first derivative $(dp/dt)$ curve of the pressure gradient curve can then be derived and the maximal positive $dp/dt$ and the maximal negative $dp/dt$ can be obtained from the pressure gradient curve. We hypothesized that if left atrial pressure fluctuation is relatively minor in comparison with corresponding left ventricular pressure changes during early systole (isovolumic contraction) and isovolumic relaxation phase, the maximal positive $dp/dt$ and the maximal negative $dp/dt$ derived from the atrioventricular pressure gradient curve should not be significantly different from those derived from the left ventricular pressure curve. This hypothesis has been demonstrated to be accurate in our previous study [6].

This in vivo study using a canine model of mitral regurgitation was designed to examine: 1) the accuracy of Doppler-derived maximal $dp/dt$ and maximal negative $dp/dt$ as compared with micromanometer catheter measurements in a variety of hemodynamic conditions and 2) reliability of the

Doppler-derived $dp/dt$ changes in predicting left ventricular functional alteration by pharmacological or hypothermal intervention.

**Methods**

*Animal preparation.* Nine adult dogs (25–34 Kg) were anesthetized with 30 mg/kg i.v. sodium pentobarbital, intubated, and ventilated using a Harvard respirator to keep blood gases within the physiological range. A left thoracotomy was performed with the animal supine. The pericardium was left open throughout the experiment. The animals were placed on right heart bypass. The venous blood was filtered, warmed and oxygenated, and then pumped by calibrated roller pump back into the dog through a wide-bore cannula inserted into the right atrium. With a second calibrated roller pump, blood could also be pumped into or removed from the systemic arterial circuit through cannulae inserted into the femoral arteries. This maneuver allowed left ventricular systolic pressure, used as an index of afterload, to be controlled relatively independently of preload [7]. The pressure catheters were inserted in the following manner: a micromanometer-tip catheter (Millar Mikro-tip, Millar Instruments, Houston, Texas) and a fluid-filled catheter connected to a pressure transducer (Statham P23DB, Statham Instruments, Oxnard, California) were inserted through the left ventricular apex to record ventricular pressure. A second micromanometer-tip catheter was inserted from a pulmonary vein into the left atrium to record left atrial pressure. A third micromanometer-tip catheter was inserted from the internal mammary artery into the aortic root to record aortic pressure.

Great care was taken to ensure the accuracy of the pressure measurements. Fluid-filled transducers were balanced at atmospheric pressure and calibrated against a mercury column. Micromanometer-tip catheters were calibrated against the zero and mean pressures recorded by the fluid-filled transducers. All pressure measurements and a single electrocardiographic lead were continuously recorded on an eight-channel strip chart recorder (Hewlett-Packard Model 7700, Hewlett-Packard, Waltham, Massachusetts). Paper speed was increased to 100 mm/sec when data for each experimental stage was formally recorded.

Mitral regurgitation was created with a grommet of a diameter of 2.8 to 4.5 mm inserted into the anterior mitral leaflet. To simulate chronic mitral regurgitation, the left atrium was enlarged by attaching a skin graft or prosthesis to the posterior wall of the atrium in 6 dogs (including one dog in which the left atrium was not enlarged at the first stage and then enlarged at following stages). This allowed a less dramatic elevation in left atrial pressure during systole, thereby simulating left atrial pressure fluctuations seen in chronic mitral regurgitation. In 4 dogs, acute mitral regurgitation was simulated by not surgically enlarging the left atrium, thereby allowing a more prominent rise (v wave) in left atrial pressure during systole.