The effect of preoperative diastolic dysfunction on outcome after surgical ventricular remodeling

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In this issue, Menicanti and colleagues¹ describe the experience with surgical ventricular restoration (SVR) procedures at the San Donato Hospital between 1989 and 2005. The study is important for a number of reasons. First, 1300 patients underwent SVR. This is the largest single-center experience to date, and the authors are to be commended for the excellent overall operative mortality of 4.7%.¹

A subgroup of 488 patients in Menicanti and colleagues' study¹ had echocardiograms before, early after (7–10 days), and late after (6 months to 2 years) SVR. In 254 patients who have undergone operations since 2001, echocardiographic measures of diastolic function, including the early-to-late mitral valve flow ratio (E/A), isovolumic relaxation time, and deceleration time (DT) of early mitral flow (E wave), were collected.¹ Normally, early flow (E wave) is higher than that associated with atrial contraction (A wave). Early diastolic dysfunction is typically associated with a reversal of the E/A ratio.² However, as diastolic compliance worsens and left ventricular end-diastolic pressure increases, the E/A ratio becomes "pseudo-normalized."³ End-stage or restrictive diastolic dysfunction is associated with an E/A greater than 2. In Menicanti and colleagues' study,¹ an E/A ratio greater than 2 was associated with early mortality after SVR. Isovolumic relaxation time and DT have also been associated with ventricular cavity stiffness; however, the effects of isovolumic relaxation time and DT were not statistically significant in Menicanti and colleagues' study. This is the first time that severe diastolic dysfunction has been identified as a risk factor for SVR.

The effect of SVR on ventricular function and the related effect of diastolic dysfunction on outcome after SVR have not been well studied until recently. However, in September, 2006, an article by Tulner and colleagues⁴ and accompanying editorial by Burkhoff and Wechsler⁵ were published in the *Journal*. The study by Tulner and colleagues was the first in which the diastolic pressure-volume relationship was measured in patients before and after SVR. The editorial by Burkhoff and Wechsler discussed SVR and its effect on left ventricular function within the framework of end-systolic pressure-volume relationship (ESPVR) and end-diastolic pressure-volume relationship (EDPVR).⁵ The readers are referred to these two excellent publications. However, to put Menicanti and colleagues' findings in context, it is important to briefly review these topics again.

The primary goal of SVR is to reduce left ventricular wall stress, and there is evidence that this occurs. For instance, Dang and colleagues⁶ used a finite element model of the left ventricle with an akinetic but contractile anteroapical left ventricular wall to calculate the mean myofiber stress after SVR and found that SVR reduces end-diastolic and end-systolic border zone and infarct myofiber stress. However, most would say that SVR should also improve pump function and would site improvements in the ejection fraction (EF) and ESPVR (slope = end-systolic elastance [E_{ES}]) as evidence that pump function is better after SVR. However, we suggest that focus on indices of systolic function *alone*, such as EF and E_{ES} , is misleading.

Pressure-Volume Relationships and Starling's Law

The study by Zhang and coworkers,⁷ from the Cardiac Biomechanics Laboratory at the San Francisco Veterans Administration, is illustrative. Zhang and colleagues

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Figure 1. The effect of surgical ventricular remodeling (SVR) procedure on E_{ES} (A), diastolic compliance (B), and Starling relationship (C). In each graph, data are shown before (open circle, ○; 12 weeks after myocardial infarction) and 6 weeks after SVR procedure in sheep (closed square, ■). Note that the Starling curve did not change significantly after the SVR procedure.⁷ LV, Left ventricular; MI, myocardial infarction.

performed patch aneurysmorrhaphy in sheep 12 weeks after transmural anteroapical myocardial infarction. Absolute left ventricular volume was measured with magnetic resonance imaging, and relative volume changes during vena caval occlusion were measured with a conductance catheter. The elliptical Dacron patch was sized to reduce the aneurysm neck by 50%. As seen in Figure 1, A, there was a large shift in the ESPVR and an increase in the E_{ES} 6 weeks after the SVR procedure. However, Figure 1, B shows that there was also a large shift in the EDPVR. As a consequence, EF increased from 21% to 34%. However, the stroke volume/end-diastolic pressure (Starling) relationship (Figure 1, C) was relatively unchanged.⁷

In 1914, Patterson and colleagues^{8,9} described the stroke volume/end-diastolic pressure and the stroke volume/end-diastolic pressure relationships. Patterson and colleagues' work was remarkable given that they did not possess cardiac imaging and relied on the displacement of water in a cylindrical container surrounding the heart as a measure of left ventricular volume. More recently, the stroke work/end-diastolic volume relationship was recommended by Glower and colleagues¹⁰ because of its linear nature. These are all acceptable measures of left ventricular pump function; however, they may not be appropriate measures of function after SVR. Specifically, we believe the stroke volume and stroke work/end-diastolic volume relationships (and EF) are poor measures of function after SVR because they directly include the left ventricular end-diastolic volume (in each case as the denominator in the equation) and therefore must

improve after SVR. However, because of its simplicity, we believe that the stroke volume/end-diastolic pressure relationship is superior for the analysis of SVR effect.

Different amounts of leftward shift of ESPVR and EDPVR will have a significant effect on the Starling relationship. For instance, in the study by Zhang and colleagues,⁷ ESPVR and EDPVR shifted similar amounts (Figure 1, A, B, arrows) after SVR, causing the postoperative Starling relationship to be unchanged. However, it can easily be seen that a slight change in either post-SVR ESPVR or EDPVR would have a significant effect on the Starling relationship. For instance, if at a given physiologic load the EDPVR shifted 5 mL further to the left on the pressure-volume plot than the ESPVR, the stroke volume and thus the Starling relationship would be decreased by 5 mL. Burkhoff and Wechsler⁵ in their recent editorial referred to this as "A balancing act on systolic and diastolic properties."

SVR in sheep with a dyskinetic infarct reduces left ventricular volume and stress but has a neutral effect on pump function.⁷ However, sheep are not patients. Specifically, despite significant ventricular remodeling, the EDPVR in sheep after anteroapical myocardial infarction remains flat and end-diastolic pressure is not elevated 12 weeks after myocardial infarction. Zhang and colleagues⁷ work requires confirmation in humans and in experimental animals with diastolic dysfunction.

In fact, Tulner and colleagues⁴ found a trend toward increased diastolic chamber stiffness from $0.021 \pm 0.009 \text{ mL}^{-1}$ to $0.037 \pm 0.021 \text{ mL}^{-1}$ and a significant increase in end-

diastolic pressure from 13 ± 6 mm Hg to 20 ± 5 mm Hg ($P < .01$) immediately after SVR. A representative plot in Tulner and coworkers' study⁴ before and after SVR showed an impressive difference in EDPVR, and Burkhoff and Wechsler⁵ estimated that EDPVR shifted 30 mL further to the left than the ESPVR. On the other hand, in a separate study of patients 6 months after SVR, Tulner and colleagues¹¹ found pulmonary artery pressures were significantly reduced from 42 ± 11 to 28 ± 10 ($P = .016$), suggesting that diastolic compliance was significantly reduced. When coupled with the data from Zhang and colleagues' study,⁷ the two studies by Tulner and colleagues^{4,11} suggest that (1) the reduction in diastolic compliance may be transient and therefore probably related to post-pump inflammation and myocardial edema and that (2) as diastolic compliance improves weeks to months after SVR, left ventricular pump function is expected to improve.

The size and shape of the restored left ventricle will also have an effect on diastolic function after SVR. SVR is not a standardized procedure. For instance, SVR can be performed with a Fontan stitch alone¹² or a patch,¹³ where patch size, shape, and orientation are variable. The factor most likely to affect diastolic function is the size of the residual left ventricular cavity. Excessive volume reduction probably causes diastolic compliance to shift further to the left on the pressure–volume curve than E_{ES} , thereby producing diastolic heart failure. This may have been the genesis of the unsatisfactory results obtained with standard linear aneurysm repair. A line of surgical manikins designed to guide the degree of volume reduction with sizes ranging from 80 to 150 mL has been marketed.^{14,15} However, at the present time there is no objective evidence to support the selection of a particular postoperative size, and, unfortunately, the Surgical Treatment for Ischemic Heart failure (STICH) trial does not proscribe a particular amount of volume reduction.¹⁶

The Effect of Preoperative Diastolic Function on Outcome

In Menicanti and colleagues' study,¹ end-stage or restrictive diastolic dysfunction (E/A ratio > 2) was associated with early mortality after SVR. Presumably, in patients with preoperative diastolic dysfunction, the slope of the EDPVR becomes unacceptably steep after SVR. We previously used a simple finite element model of the left ventricle to determine the effect of preoperative diastolic stiffness on ESPVR, EDPVR, and the Starling relationship after partial ventriculectomy.¹⁷ In all cases, the partial ventriculectomy was depressed after partial ventriculectomy; however, the smallest decrement was associated with the highest diastolic stiffness.¹⁷ This suggests that the effect of preoperative diastolic dysfunction may not be on pump function but that the slope of the EDPVR per se is responsible for poor outcomes. It will be important to measure the effect of SVR on

the ESPVR, EDPVR, and Starling relationship in patients with mild to moderate preoperative diastolic dysfunction. It is also unknown whether and to what extent preoperative diastolic dysfunction is additive to the diastolic effects of postoperative myocardial edema and to the change in EDPVR associated with left ventricular volume reduction.

National Institutes of Health STICH Trial and Diastolic Function

The National Institutes of Health–sponsored STICH trial¹⁶ is a multicenter randomized comparison of medical therapy versus coronary bypass surgery for patients with congestive heart failure and an EF less than 35%. STICH includes SVR + coronary artery bypass grafting as a treatment arm in patients with a left ventricular end-systolic volume index greater than 60 mL/m² and akinesia greater than 35% of the anterior left ventricular wall. Patients in the STICH trial will also have echocardiographic measurement of diastolic dysfunction including E/A ratio, DT, in addition to left atrial volume, and tissue Doppler measurement of early diastolic mitral annular velocity (J. K. Oh, MD, personal communication, January 2007, STICH Echo Core Laboratory). These important data may be available as early as 2008.

Conclusions

SVR reduces wall stress, but the effect on left ventricular pump function remains unclear. Pre- and post-SVR ESPVRs and EDPVRs are useful ways to visualize the effect of SVR on stroke volume, and in that regard we suggest that the stroke volume/end-diastolic pressure relationship is the best measure of post-SVR function.

The effect of SVR on diastolic function was recently the focus of two studies by Tulner and colleagues^{4,11} and an editorial by Burkhoff and Wechsler.⁵ Diastolic compliance appears to be reduced early after SVR, leading to a reduction in stroke volume. These effects may be from postoperative edema because pulmonary pressures late after SVR are significantly reduced. The size of the residual left ventricular cavity may have a significant effect on postoperative diastolic function, but this has been well studied and the STICH trial does not proscribe specific amounts of volume reduction to participating surgeons.

Finally, the study in the current edition of this journal by Menicanti and colleagues¹ provides important new information about diastolic function. Menicanti and colleagues' study is the largest single-center study to date, and it is the first to suggest that patients with preoperative diastolic dysfunction may have worse outcome after SVR. The mechanism of this effect is unclear, and future studies should include the measurement of EDPVR before and after SVR in patients and animals with diastolic dysfunction. Finally, the analysis of echocardiographic measures of diastolic function from the STICH trial will be extremely valuable.

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