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EDITORIAL COMMENT

Batista's Operation: What Have We Learned?*

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Partial left ventriculectomy (PLV) was initially performed by Brazilian surgeon Randas Batista (1) with the rationale that resection of a viable "slice" of the lateral left ventricular (LV) wall in patients with dilated cardiomyopathy (DCM) would reduce LV diameter and therefore wall stress (2). Although early results with this procedure in uncontrolled trials were promising and generated significant enthusiasm (2), outcomes of subsequent clinical results have been mixed (3).

This issue of the *Journal* includes two articles that describe clinical outcomes after Batista's operation. The article by Schreuder et al. (4) describes the effect of PLV on

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LV pressure, volume and wall stress in eight patients immediately before and after PLV, whereas the article by Starling et al. (5) describes the effect of PLV on right heart pressures and flow, LV pressure and volume, and exercise capacity in 18 event-free survivors (freedom from death, left ventricular assist device, or return of New York Heart Association [NYHA] functional class IV failure) one year after PLV (59 original operations). These studies present us with an opportunity to reassess the physiologic rationale for PLV and to determine future research and therapeutic directions.

Both studies are nonrandomized clinical trials in patients with NYHA class III–IV heart failure. Of note, in most cases PLV was accompanied by mitral valve repair (88% to 93%) (4,5). Schreuder et al. (4) describe significant reductions in volume index at end-diastole (LVEDVI) and peak wall stress after PLV. Starling et al. (5) conclude that, although LVEDVI was significantly decreased and NYHA class and peak VO_2 rose significantly in event-free survivors, there were minimal changes in stroke volume, cardiac index, mean pulmonary, and pulmonary capillary wedge pressures. The basis for the increase in VO_2 is therefore unclear and may be from improved medical management or placebo effect (5).

Volume and stress reduction. The ability of the conductance catheter to measure absolute LV volume as used by Schreuder et al. (4) is of concern. Measurement of LV volume with the conductance catheter has been described by Baan et al. (6) and includes calibration of the catheter against a known flow standard and measurement of parallel conductance (V_p). However, even with careful calibration and frequent V_p measurement, the conductance catheter may not be a good measure of absolute LV volume. The V_p may vary with LV end-diastolic volume (7). In addition, the amount of saline in the pericardial space (8), metal sternal retractors (9) and temperature (10) all have been shown to affect V_p. As an example, Figure 1 is a measure of agreement (11) between stroke volume measured by thermodilution and stroke volume measured with the conductance catheter constructed from the data (Table 2) of Schreuder et al. (4). This analysis shows a mean difference of approximately 20 ml and multiple differences greater than 40 ml. The relative contribution of V_p and calibration to this error is unknown. However, it would seem reasonable to corroborate conductance catheter measures of absolute LV volume with echocardiography or nuclear radiography whenever possible and use the conductance catheter for relative volume changes only (12,13). Nonetheless, the decrease in LV volume reported by Schreuder et al. (4) is large, and earlier reports have consistently documented a decrease in end-diastolic and end-systolic LV volumes with PLV (14,15).

It also seems reasonable that PLV reduces LV wall stress. However, the stress calculation described by Arts et al. (16) and used by Schreuder et al. (4) is based on a thick-walled sphere and assumes that muscle fiber stress and strain are homogeneously distributed in the normal LV. Furthermore, the LV undergoes a significant shape change after partial ventriculectomy and stress may not be uniformly distributed in the dilated LV before or after partial ventriculectomy. Certainly, in the region of the surgical incision there may be local stress concentration and tethering of the area around the suture line. Also, this analysis ignores any contribution from increased residual stress after partial ventriculectomy. Therefore, the wall-stress calculations are a gross simplification and probably add nothing beyond the individual pressure and volume data. Only finite element simulations (see subsequent text) are able to take into consideration nonuniform geometry, local differences in myocardial stiffness and residual stress (17).

Failure to improve LV function. The reduction in LV volume and wall stress accomplished by PLV may not be sufficient to improve LV function. For instance, early reports documented a heterogeneous effect of partial ventriculectomy on ventricular function (18,19). Although most reports document a decrease in stroke volume (14,15), stroke volume and cardiac index (19) also have been noted to improve. However, because postoperative ventricular end-diastolic pressure often varies widely (14,19) and heart rate is increased (14), these data are difficult to interpret. In

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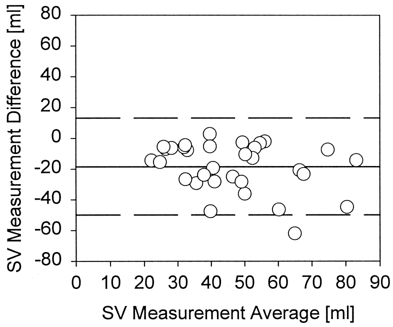

Figure 1. Measure of agreement between stroke volume measured by thermodilution and stroke volume measured with the conductance catheter constructed from the data of Schreuder et al. (4) (Table 2). Note the mean difference of 18.4 ml.

addition, concomitant mitral valve repair makes static data almost impossible to interpret.

We suggest that the success of an operation that surgically remodels LV size, shape or regional stiffness depends on how the procedure affects *both* end-systolic pressure-volume (elastance) and diastolic pressure-volume (compliance) relationships, and how those changes affect ventricular function (e.g., stroke volume vs. end-diastolic pressure [Starling] relationship) (20). The effect of partial ventriculectomy on load independent end-systolic and diastolic pressure-volume relationships has been measured with ventriculography (21), conductance catheter (15) and two-dimensional echocardiography (18). End-systolic elastance has been found to increase by two- to threefold (15,21) and diastolic compliance significantly decreases (15,18). However, the Starling relationship has not been measured.

Mathematical (finite element) models. Finite element analysis (FEA) relates regional material properties, structural shape and regional stress as a system of linear equations (22). Given accurate initial conditions, FEA is able to include nonuniform geometry, local differences in myocardial stiffness and residual stress and then calculate the effect of LV volume-reduction surgery on end-systolic elastance, diastolic compliance and ventricular function (17). Given the lack of a large animal model of dilated cardiomyopathy suitable for experimental testing, finite element modeling may provide the best analysis of PLV. It may also provide a test bed with which to evaluate new operations for dilated cardiomyopathy.

We have previously described a simple finite element model of partial left ventriculectomy (17). That simulation shows that PLV causes diastolic compliance to shift farther to the left on the pressure-volume diagram than end-systolic elastance. As a consequence, PLV decreases the slope of the Starling relationship, suggesting that PLV decreases cardiac pump function. These predicted relative shifts in the LV compliance and elastance have been corroborated by the experimental studies of Kawaguchi et al. (15) and the mathematical multicompartment model of Dickstein et al. (23), which also confirmed depression of the Starling relationship.

Of note, an improvement in ejection fraction (EF) or preload recruitable stroke work (PRSW) does not mean that PLV is successful. Although EF has consistently increased (14,19), mathematical models predict a decrement in the Starling relationship even when EF and PRSW are improved (17,23). Independent variables, such as EF or PRSW, that are mathematically dependent on changes in LV volume and must change when LV volume is reduced are poor predictors of LV function in the setting of ventricular remodeling surgery.

Statistical issues. Repeated measures analysis of variance (ANOVA) typically excludes cases with missing data. Although techniques exist to estimate small amounts of missing data (24), the amount of missing data (Table 2; 3 of 8 complete data sets) in Schreuder et al. would seem to preclude a meaningful repeated measures analysis (4).

Also of concern are the statistical methods employed by Starling et al (5). Specifically, patients who do well (event-free) are selected over time, and while it appears in this series that volume, EF and exercise tolerance were stable, this may not be the case for the entire group. We would like to learn from Batista's operation, and although it is interesting to know the characteristics of event-free survivors, of more interest might be the characteristics of those in whom the operation failed. Survival analysis may be a more appropriate way to test factors that are related to early postoperative deterioration in pump function and late postoperative redilation (see subsequent text) (25).

Clinical outcomes. Short- and mid-term follow-up from the Cleveland Clinic has been previously reported (3). Operative mortality was 3.2% and 16% (10/62) of patients who required LVAD placement for cardiogenic shock. Survival was 78% and 68%, but event-free survival was only 50% and 37% at one and two years, respectively (3).

Because a control group was not employed, it is instructive to consider the outcomes of patients with NYHA class III–IV heart failure treated with other therapies. For instance, beta-blocker therapy has significantly reduced the mortality of NYHA class III–IV heart failure. Recent studies including CIBIS-II (mortality [mean follow-up 1.3 years]: placebo 17.3%, Bisoprolol 11.8%) (26) and COPERNICUS (annual mortality: placebo 18.5%, Carvedilol 11.4%) (27) were both stopped early because of significant mortality benefit. In addition, mitral valve repair alone has one- and two-year survivals of 82% and 71% in NYHA class III–IV heart failure (28). Because survival rates are so similar, it would seem reasonable to randomize future studies (i.e., beta-blockers vs. PLV + beta-blockers) so that the most effective therapies can be determined.

Postoperative redilation. Patients who have undergone both left ventricular (LV) patch aneurysmorrhaphy (29) and PLV (19) have experienced LV dilation at one year. Dor et al. found that end-systolic and end-diastolic ventricular volume increased 22% and 29%, respectively, after patch repair (29), and Moreira et al. reported that end-systolic and end-diastolic ventricular volume increased after PLV (19).

The cause of this postoperative remodeling is unclear but may include progression of the underlying biologic disease process, infarction and stretching at the suture line, lack of pericardial support and increased wall stress secondary to the aneurysm repair. Of note, a recent report documented scar (suture line) expansion after PLV (30).

Conclusions. Batista's operation was an intriguing and potentially important surgical therapy for patients with dilated cardiomyopathy and congestive heart failure. Partial left ventriculectomy is able to reduce LV volume and probably decreases ventricular wall stress. However, reduction of volume and stress is not sufficient to improve ventricular function. Specifically, finite element simulations of partial left ventriculectomy show that diastolic compliance shifts further to the left on the pressure-volume diagram than end-systolic elastance. The net result is a decrement in the Starling relationship. Peri-operative data are difficult to interpret, but in general they are consistent with these predictions.

In addition, clinical results have been disappointing. Event-free survival is poor (37% at two years) (3). Furthermore, because clinical trials were not randomized, it is not clear that surgical results are different from those obtained with current state-of-the-art medical and surgical therapy.

The apparent failure of partial left ventriculectomy does not imply that all surgical operations that intend to reduce the dilated LV are impractical. For instance, the Myocor interventricular splint and surgical procedures that restore ventricular shape after post-infarction remodeling such as the Dor procedure (29) and radiofrequency infarct heating (31) may reduce stress without a reduction in ventricular function.

As discussed, finite element simulations may serve as a useful test bed with which to evaluate new operations for dilated cardiomyopathy. In addition, improvements in technology may allow the noninvasive measurement of material properties in the future. For instance, Moulton et al. (32,33) have back-calculated myocardial material properties from magnetic resonance measurements of myocardial strain. We hope that, in the future, knowledge of regional material properties may serve as input into mathematical simulations allowing surgeons to individualize design of reparative operations for patients with dilated cardiomyopathy and congestive heart failure.

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