Effects of Surgical Ventricular Restoration on Left Ventricular Contractility Assessed by a Novel Contractility Index in Patients With Ischemic Cardiomyopathy

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A pressure-normalized left ventricular (LV) wall stress ($d\sigma^*/dt_{max}$) was recently reported as a load-independent index of LV contractility. We hypothesized that this novel contractility index might demonstrate improvement in LV contractile function after surgical ventricular restoration (SVR) using magnetic resonance imaging. A retrospective analysis of magnetic resonance imaging data of 40 patients with ischemic cardiomyopathy who had undergone coronary artery bypass grafting with SVR was performed. LV volumes, ejection fraction, global systolic and diastolic sphericity, and $d\sigma^*/dt_{max}$ were calculated. After SVR, a decrease was found in end-diastolic and end-systolic volume indexes, whereas LV ejection fraction increased from 26% ± 7% to 31% ± 10% ($p < 0.001$). LV mass index and peak normalized wall stress were decreased, whereas the sphericity index (SI) at end-diastole increased, indicating that the left ventricle became more spherical after SVR. LV contractility index $d\sigma^*/dt_{max}$ improvement (from 2.69 ± 0.74 to 3.23 ± 0.73 s^{-1}, $p < 0.001$) was associated with shape change as evaluated by the difference in SI between diastole and systole ($r = 0.32$, $p < 0.001$, preoperative; $r = 0.23$, $p < 0.001$, postoperative), but not with baseline LV SI. In conclusion, SVR excludes akinetic LV segments and decreases LV wall stress. Despite an increase in sphericity, LV contractility, as determined by $d\sigma^*/dt_{max}$, actually improves. A complex interaction of LV maximal flow rate and LV mass may explain the improvement in LV contractility after SVR. Because $d\sigma^*/dt_{max}$ can be estimated from simple noninvasive measurements, this underscores its clinical utility for assessment of contractile function with therapeutic intervention. **(Am J Cardiol 2009;103:674–679)**

We recently demonstrated the efficacy of a novel left ventricular (LV) contractility index, maximal rate change of pressure-normalized wall stress ($d\sigma^*/dt_{max}$), that correlates well with maximal LV dP/dt.[1] Pressure-normalized wall stress (σ^*) represents LV physical response to loading and allows comparison between ventricles at different pressures. Our previous study showed that this index is easily measured noninvasively, is sensitive to LV inotropic changes, and appears to be relatively independent of preload and afterload.[1] It is measured at a single steady-state condition rather than the multiple variably loaded cardiac cycles required for many other indexes.[2,3] The value of magnetic resonance imaging (MRI) in the treatment of heart failure is becoming established in initial functional assessment with excellent interstudy reproducibility that allows the technique to determine treatment outcomes.[4] Furthermore, accurate measurement of mitral annular dimensions and mitral regurgitation severity can be performed using MRI, allowing planning of effective therapy for ischemic mitral regurgitation. Contemporary application of MRI in clinical practice is facilitated by semiautomated image processing software, which has substantially decreased the time required for analysis.[5] The aims of this study were to retrospectively evaluate the changes of LV contractile function by means of $d\sigma^*/dt_{max}$ and to determine LV shape change and wall stress before and after surgical ventricular restoration (SVR).

Methods

Patients: We performed a retrospective analysis of MRI data of 40 patients with ischemic cardiomyopathy who had undergone coronary artery bypass grafting combined with SVR. In some of these patients, there had been concomitant mitral regurgitation that required mitral valve repair surgery by means of restrictive mitral annuloplasty. In each, the SVR procedure was performed by means of endoventricular circular patch plasty as described by Dor et al.[6] All patients underwent a full MRI protocol before and after SVR. The study was approved by the Cleveland Clinic institutional review committee and all patients gave informed consent.

Magnetic resonance imaging: MRI studies were performed 1 week to 2 weeks before surgery and 1 week to 2

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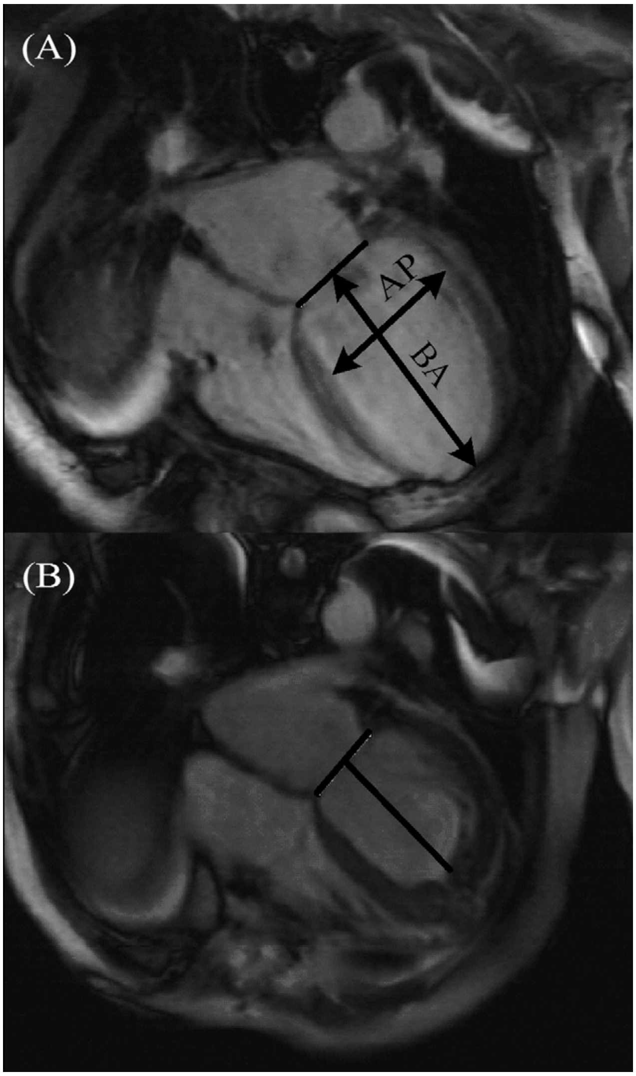

Figure 1. Long-axis MR images of a patient before *(A)* and after *(B)* SVR. Multiple short-axis cine images from the apex to the base of the heart (or orientated axial) and long-axis cine images are used to quantify LV function. Anterior to posterior (AP) and base to apex (BA) were measured from 2-dimensioal MRI before and after SVR during the cardiac cycle. The SI was calculated as AP/BA.

weeks after surgery on a 1. 5-T MRI scanner (Siemens Somatom, Erlangen, Germany) equipped with fast gradients (23-mT/m amplitude, 105-mT/m/ms slew rate) and a dedicated cardiac phased-array surface coil. Electrocardiographically gated consecutive cine short-axis views were acquired to cover the left ventricle using a breath-held steady-state free-precession technique (echocardiographic time 1.4 ms, repetition time 2.9 ms, slice thickness 8 mm, flip angle 60°, spatial resolution 1.4×1.2 mm^2, and temporal resolution 42 ms). Vertical and 1 horizontal long-axis views were obtained to assess the LV apex. MRI studies were reviewed on a commercially available computer workstation. Volumetric analysis (Simpson method of discs) of the short-axis cine MRI images yielded LV end-diastolic volume, end-systolic volume, stroke volume, ejection fraction, and LV mass.

Data analysis: For analysis, images were displayed on a computer monitor in a cine-loop mode using commercially available software (CMRtools, Cardiovascular Imaging Solution, London, United Kingdom). We analyzed all frames to produce an LV volume curve from end-diastolic to end-systolic phases. This was used to determine end-diastolic volume, end-systolic volume, stroke volume, ejection fraction, and LV mass. To provide information on intraobserver and interobserver reproducibilities, analysis of a patient's scan was performed 2 times in 10 subjects by 1 investigator and 1 time by a second investigator. All analyses were performed in random order with investigators blinded to previous results.[7]

A 6-order polynomial function was used to curve fit the volume–time data and to calculate the derivative (i.e., dV/dt). The LV contractility index $d\sigma^*/dt_{max}$ was calculated using the formula $1.5 \times (dV/dt_{max})/V_m$, where V_m is myocardial volume at the end-diastolic phase. Preoperative and postoperative global LV shape was assessed by calculating the sphericity index (SI) in diastole and systole using the formula SI = AP/BA, where BA, the LV long axis, was defined as the longest distance from the apex to the base of the left ventricle (defined as the mitral annular plane), as measured on the 4-chamber cine MRI view of the heart, and AP was defined as the widest LV minor axis (Figure 1). A small value of SI implies an ellipsoid left ventricle, whereas values approaching 1 suggest a more spherical left ventricle. The SIs at end-diastole and end-systole, percent shortening of the long and minor axes, and the difference between end-diastolic and end-systolic values of SI were calculated. The time-varying circumferential normalized wall stress, NSW(t), was calculated from instantaneous measurements of LV dimensions and wall thickness by treating the left ventricle as a prolate spheroid model truncated 50% of the distance from the equator to the base as suggested by Streeter and Hanna[8]: $NWS(t) = AP(t)/2h(t) \times (1 - [\{9AP(t)/32h(t) \times SI^2\}/\{AP(t)/h(t) + 1\}])$. Wall thickness, h(t), was calculated from the following formula assuming that wall volume remains constant throughout the cardiac cycle: $9/8 \times ([\{BA(t)/1.5\} + h(t)] \times [\{AP(t)/2\} + h(t)]^2) = V_m(t) + BA(t)/1.5) \times (AP(t)/2)^2$.

Statistical analysis: All continuous variables were presented as mean ± SD. Intraobserver and interobserver reproducibilities were assessed by calculating the mean difference ± SD between results, with percent variability equal to the mean of the absolute values of the differences between the 2 measurements divided by their mean. Student's paired *t* test was used to assess any significant differences between measurements. The correlation coefficient was calculated to assess the strength of the relation. Multivariate general linear model was performed to determine differences between patients with and without congestive heart failure and between those with and without mitral valve repair surgery on the continuous variables before and after SVR. Associations among variables were explored using Pearson or Spearman rank correlation coefficient, as appropriate. A p value <0.05 was considered statistically significant. A commercially available statistical software package was used for data analysis (SPSS 15, SPSS, Inc., Chicago, Illinois).