Diabetic cardiomyopathy (DCM) has been recognized in diabetic patients who develop heart failure in the absence of hypertensive, ischemic, or significant valvular diseases (1–3). Diabetes is not only an independent risk factor (4), but also an adverse prognostic indicator of heart failure (5). Accordingly, an important challenge is to identify the earliest manifestations of heart disease with the use of objective surrogate markers of cardiac dysfunction and ultimately to prevent heart failure by instituting earlier therapy. Diastolic dysfunction has been described as an early stage of DCM in diabetics with normal left ventricular (LV) ejection fraction (6,7). However, the general acceptance of isolated diastolic dysfunction as the earliest abnormality in diabetic patients also might reflect the insensitive nature of the criteria for identifying abnormal LV systolic function according to ejection fraction.

Recently, more sensitive methods have been applied to assess systolic function. Tissue Doppler strain and strain rates have been used not only to characterize systolic function in diabetics who have normal LV function, but also to evaluate other clinical covariates such as hypertension, hypertrophy, use of beta-blockers or calcium channel blockers, and the dependence on glycemic control (8–10). Unfortunately, little is known about systolic contractile dysfunction in the earliest stages of DCM, at which time LV ejection fraction, mass, and blood pressure may be minimally affected under conditions of tight glycemic control. To gain a more thorough understanding of systolic function in the very early stage of DCM, subclinical features preceding overt hypertrophy require evaluation. Also, potentially confounding influences of hypertension, poor glycemic control, beta-blockers, calcium channel blockers, and heart rate (HR) require assessment.

Doppler strain and strain rate echocardiography are simple and quick to perform and reveal information about cardiac strain not available by traditional echocardiography. However,
the method is restricted to one-dimensional deformation from a fixed point in space and does not track myocardial motion. It also depends on the angle between the beam direction and tissue deformation. In contrast to Doppler strain echocardiography, magnetic resonance imaging (MRI) myocardial tagging techniques track the motion of a specific point within the myocardium and allow comprehensive two- and three-dimensional evaluation of regional and global cardiac tissue deformation (11,12).

The regional contractile patterns of the ventricle measured by tagging provide twist, torsion, and strain data that are informative regarding mechanisms of local tissue deformation. Torsion reports the rotation of the apex with respect to the base along its long axis and is produced by contraction of the heart’s obliquely spiraling myocardial layers. A period of rapid untwisting recoil follows maximal torsion and occurs largely during isovolumic relaxation (13,14). The maximal torsion rate during recoil (TR-r) has been shown to correlate with the time constant of relaxation, tau (13). We propose that MRI tagging should provide a reproducible and sensitive method for quantifying twist, torsion, strain, and their corresponding rates in early diabetic heart disease. Thus, we hypothesized that subtle manifestations of abnormal ventricular torsion, torsion rate, and strain might appear early in DCM and be detectable with MRI tagging in type I diabetics who have normal ejection fraction, normal LV mass, normal blood pressure, tight glycemic control, and no overt heart disease. Because diabetic patients are known to have higher HRs at rest, we also sought to define the impact of isolated chronotropic stimulation on myocardial torsion as compared with increased inotropic stimulation induced by exercise at comparable HRs to evaluate this feature as a potential covariate for any observed cardiac dysfunction.

**METHODS**

**Patients.** We studied 35 patients (16 with and 19 without type I diabetes mellitus). To ensure tight glycemic control and homogeneity, the diabetic group consisted of adults with type I diabetes who were followed up regularly at the Washington University diabetes clinic and met the inclusion criteria: age 18 to 50 years, no symptoms or signs of known heart failure, duration of type I diabetes ≥5 years, on insulin therapy, hemoglobin A1c (HbA1c) ≤7.5% within the last three months. We excluded those with abnormal LV function, hypertrophy, moderate to severe valvular abnormalities, or wall motion abnormalities noted on transthoracic echocardiography (TTE) or cine MRI; hypertension; severe arrhythmias; congenital heart diseases; history of coronary artery disease; other significant illnesses; or the standard contraindications for MRI (15). The control patients comprised two groups: control 1, normal volunteers to compare with the diabetic patients, and control 2, normal volunteers to study HR effects. All patients gave informed consent, and the study protocol was approved by the Human Studies Committee at Washington University Medical Center. Each diabetic patient and control 1 patient underwent TTE followed by MRI. The control 2 patients underwent MRI only.

**Transthoracic echocardiogram.** Complete two-dimensional and color Doppler examinations were obtained (Acuson XP128, Siemens, Germany). The transmitial inflow pulse-wave Doppler was obtained in the apical four-chamber view, including the E-wave (early mitral inflow velocity), the A-wave (peak atrial filling velocity), the E/A ratio, and deceleration time (DT, time from peak of the E-wave to baseline). The tissue Doppler images at the septal and lateral mitral annulus were obtained to assess peak myocardial early diastolic velocity (Em) and peak myocardial late diastolic velocity (Am). Diastolic dysfunction was defined if one of the following criteria was met: E < A or >2 × A, DT >220 ms or <160 ms, isovolumic relaxation time >100 ms or <70 ms, or average Em <8 cm/s.

**Cine MRI imaging protocol.** All MR imaging was performed with a 1.5-T scanner with a five-element, phased-array coil (ACS NT, INCA software, Philips Medical Systems, Best, the Netherlands). A standard ventricular function examination was performed by acquiring cine-loops of vertical long-axis, horizontal long-axis, LV outflow tract, and short-axis stack views with a vector electrocardiogram-triggered steady-state gradient echo sequence. Acquisition parameters were: repetition time (TR), 3.2 ms; echo time (TE), 1.6 ms; flip angle, 60°; field of view, 320 mm; acquisition matrix, 160 × 256; slice thickness, 10 mm.

**Tagged MRI imaging protocol.** **DIABETICS AND CONTROL 1 PATIENTS: DCM.** For diabetics and control 1 patients, tagged images were obtained at basal and apical short-axis slices perpendicular to the LV long axis. Two sets of Complementary Spatial Modulation of Magnetization pulses were applied sequentially at end diastole after the R wave of the triggering electrocardiogram. Stripe tags in two orthogonal directions yielded a tag grid of an 8-mm spacing. Immediately after the tagging sequence, gradient echo cine images were obtained through the entire cardiac cycle to follow the placement of the tags. The imaging parameters were: TE, 5 to 6 ms; field of view, 350 mm; data matrix, 115 × 256; and slice thickness, 7 mm. The TR was adjusted to the R-R interval so that a total of 25 frames were acquired during one cardiac cycle.

**Abbreviations and Acronyms**

DCM = diabetic cardiomyopathy  
ES = duration from end-diastole to end-systole  
HbA1c = hemoglobin A1c  
HR = heart rate  
LV = left ventricle/ventricular  
MRI = magnetic resonance imaging  
TR-r = maximal torsion rate during recoil  
TR-s = maximal torsion rate during systole  
TTE = transthoracic echocardiography
CONTROL 2 PATIENTS: HR EFFECT. The control 2 patients underwent cine and tagged MRI. Tagged images were acquired at the short-axis apex initially at rest. Then the patient exercised on a supine bicycle already fitted to the scanner until the HR reached 30% above baseline. Post-exercise tagged apical images were acquired rapidly before HR decreased. Care was taken to acquire tagged images at the same apical slice level for the control 2 patients by pre-planning and fixing the slice position in the scanner. After recovering until the HR reached baseline, the participant then received an atropine injection of 0.4 mg initially. An additional 0.2 mg was given every two minutes (up to a total of 1.2 mg) until the HR reached 30% above baseline. Post-atropine tagged images were acquired. The total administration was similar to doses used during a dobutamine/atropine stress test. The HR, pulse oximetry, and symptoms were continuously monitored. Blood pressure was monitored every 30 to 45 s.

POSITIONAL VARIABILITY OF TORSION. The sensitivity of torsion measurements to small basal-to-apical shifts in the location of myocardial slices is unknown. To determine how much patient movement might affect data quality after supine bicycle exercise, additional tagged images were obtained at rest in one patient at three partially overlapping, adjacent apical slices, offset by half of the slice thickness (3.5 mm). Torsion and strain values were compared in these three slices.

Supine bicycle exercise. The supine bicycle ergometer was fitted to the patient table in the MRI scanner and received the electrocardiogram signals from the MRI scanner (Lode MRI Ergometer, Lode BV, Groningen, the Netherlands). The control 2 patients exercised on the supine bicycle on the MRI Ergometer, Lode BV, Groningen, the Netherlands). Endocardial and epicardial borders were manually traced from base to apex in each image. Endocardial and epicardial borders were manually traced from base to apex in each temporal frame of the short-axis cine images. The contours were then stacked to yield LV ejection fraction, volumes, and mass. The LV mass was calculated by multiplying the volume of tissue between the epicardial and endocardial borders by the density of cardiac tissue, 1.05 g/ml. Two orthogonal diameters were obtained at a mid-ventricular short-axis slice along the septal-lateral axis (D1) and along the anterior-inferior axis (D2). The eccentricity index was then calculated from the average of D1 and D2 divided by the LV length between mitral annulus and apex on a four-chamber image. The D1, D2, LV length, and eccentricity index were obtained at end-diastole and end-systole.

LONGITUDINAL LV SHORTENING. From four-chamber cine images, mitral valve plane motion was defined as the difference between end-diastolic LV length and end-systolic LV length. Longitudinal LV shortening rate was obtained by dividing longitudinal LV shortening by the time elapsed from end diastole to end systole.

TORSION, TORSION RATE, AND CIRCUMFERENTIAL STRAIN. Conventional homogeneous strain analyses were performed with a MATLAB-based (MathWorks, Natick, Massachusetts) Cardiovascular MR Image Analysis Tool developed and validated in our laboratory (16). Finite element approaches were used by dividing myocardium into triangular elements using adjacent tag points. Two-dimensional Lagrangian strain tensor E was computed for each triangle using the method outlined by Fogel et al. (17). Circumferential strain was derived. Myocardial twist was computed relative to the centroid of the ventricular mass at end diastole (16). Torsion was obtained by dividing net twists between base and apex by ventricular length for diabetic and control 1 patients. For the control 2 patients, the apical twist was divided by the length between the mitral valve plane and apex to produce torsion. Maximal torsion corresponded to the end-systolic torsion. Torsion rate was defined as the rate of change in torsion over time. Maximal torsion rate was obtained during systole (TR-s) and recoil (TR-r). Torsion and torsion rate over cardiac cycle for each patient were normalized by time to reach maximal torsion (%ES) to allow comparison among patients with different HRs.

Statistical analysis. Continuous data were expressed as mean values ± standard deviation. Differences between diabetic and control 1 patients were assessed by the Mann-Whitney rank-sum test. In the control 2 patients, the Wilcoxon signed rank test was used to compare the paired samples in each patient (baseline vs. post-atropine, baseline vs. post-exercise, post-atropine vs. post-exercise). Friedman statistics were used to detect any significant differences among all three groups of data (baseline, post-atropine, and post-exercise). Correlation coefficients were calculated to determine association between predictor variables, including age, duration of diabetes, body mass index, body surface area, HbA1c, HR, maximal torsion, TR-s, and TR-r. Multivariate linear regression models were constructed using predictor variables with significant correlation coefficients to predict maximal torsion, TR-s, and TR-r. Statistical tests were conducted using Microsoft Excel and SPSS (version 13.0, SPSS Inc., Chicago, Illinois). A value of p < 0.05 was considered significant. All tests were two-tailed.

RESULTS

Patient characteristics. The clinical characteristics are shown in Table 1. The duration of diabetes was 22.9 ± 9.2 years, ranging from 8 to 37 years. In all diabetic patients, aggressive glycemic control was achieved on insulin (HbA1c, 6.8 ± 0.4%). Other medications included angiotensin- converting enzyme inhibitors for renoprotection (n = 3), 3-hydroxy-3-methyl-glutaryl-CoA reductase inhibitor (n = 1), and aspirin (n = 2). No control patients were on any medication. Type I diabetics and control 1 patients were
similar in age, blood pressure, body mass index, and body surface area. However, resting HR was significantly increased in diabetics compared with control 1 patients.

**TTE results.** All patients had normal systolic function and no significant valvular abnormalities. Only three diabetics met the criteria of diastolic dysfunction by TTE. Two diabetics had E/A < 1. Another diabetic had isovolumic relaxation time > 100 ms. All three of these had Em < 8 cm/s.

**Cardiac function and tagged MRI results.** Diabetics and control 1 patients were similar in LV ejection fraction, LV mass/body surface area, end-diastolic volume, and end-systolic volume. No significant differences were observed in eccentricity index at both end diastole and end systole. Longitudinal shortening, circumferential strain, and their corresponding rates were also comparable (Table 2). The control 1 and the control 2 patients at rest also were similar in LV ejection fraction, LV mass/body surface area, twist, and circumferential strain at apex.

Maximal torsion was 23% greater in diabetic patients (3.5 ± 0.9°/cm vs. 2.7 ± 0.4°/cm; p = 0.005). Torsion remained elevated throughout systole, isovolumic relaxation, and early diastole (Fig. 1). Segmental torsion differences did not reach statistical significance (Fig. 2). The TR-s was 25% higher in diabetics compared with control 1 patients (0.013 ± 0.003°/cm/s vs. 0.010 ± 0.002°/cm/s, p = 0.01). The TR-r was 31% higher in diabetics at 120% ES, but with a borderline statistical significance (−0.020 ± 0.009°/cm/s vs. −0.014 ± 0.005°/cm/s, p = 0.07) (Fig. 3). Linear regression analysis showed significant correlation only between HbA1c and TR-s (p = 0.002) (Fig. 4). Multivariate regression showed no interaction among the variables.

**THE HR EFFECT.** The control 2 patients comprised nine men (mean age, 32.8 ± 10.1 years). The mean HR at baseline was 66.7 ± 9.7 beats/min, significantly lower than

---

**Table 2.** Functional and Tagged Magnetic Resonance Imaging Results

<table>
<thead>
<tr>
<th></th>
<th>Type I Diabetics</th>
<th>Control 1 Patients</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV ejection fraction (%)</td>
<td>64.2 ± 4.4</td>
<td>64.1 ± 3.4</td>
<td>0.73</td>
</tr>
<tr>
<td>LV mass/BSA (g/m²)</td>
<td>49.6 ± 9.3</td>
<td>55.6 ± 10.1</td>
<td>0.19</td>
</tr>
<tr>
<td>EDV (ml)</td>
<td>140.1 ± 31.6</td>
<td>150.7 ± 19.8</td>
<td>0.21</td>
</tr>
<tr>
<td>ESV (ml)</td>
<td>50.5 ± 14.3</td>
<td>54.5 ± 11.1</td>
<td>0.37</td>
</tr>
<tr>
<td>Longitudinal shortening (cm)</td>
<td>1.5 ± 0.3</td>
<td>1.5 ± 0.5</td>
<td>0.98</td>
</tr>
<tr>
<td>Longitudinal shortening rate (cm/s)</td>
<td>3.9 ± 1.0</td>
<td>3.5 ± 1.4</td>
<td>0.30</td>
</tr>
<tr>
<td>Circumferential strain at apex</td>
<td>−0.18 ± 0.03</td>
<td>−0.19 ± 0.02</td>
<td>0.32</td>
</tr>
<tr>
<td>Circumferential strain at base</td>
<td>−0.15 ± 0.02</td>
<td>−0.15 ± 0.03</td>
<td>0.56</td>
</tr>
<tr>
<td>Maximal torsion (degree/cm)</td>
<td>3.54 ± 0.90</td>
<td>2.73 ± 0.40</td>
<td>0.005</td>
</tr>
<tr>
<td>Maximal TR-s (degree/cm/s)</td>
<td>0.013 ± 0.003</td>
<td>0.010 ± 0.002</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximal TR-r (degree/cm/s)</td>
<td>−0.020 ± 0.009</td>
<td>−0.014 ± 0.005</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>p=0.79</th>
<th>p=0.71</th>
</tr>
</thead>
</table>

---

**Figure 1.** Torsion during cardiac cycle. Significant torsion differences between diabetics and control 1 patients during systole, isovolumic relaxation, and early diastole (p < 0.05). At end systole (100% ES), diabetics had a 23% increase in torsion compared with the control 1 patients. %ES = percent systolic duration. **Solid squares** = control 1 patients (n = 10); **open squares** = diabetics (n = 16).

**Figure 2.** Global and segmental torsion. Global torsion was significantly higher in diabetics (p = 0.01). However, segmental torsion differences were not statistically significant. **Solid bars** = control 1 patients (n = 10); **open bars** = diabetics (n = 16).
88.0 \pm 10.5 \text{ beats/min post-atropine (p < 0.01)}, and 85.7 \pm 10.0 \text{ beats/min post-exercise (p < 0.01) (Table 3). Chronotropic stimulation did not alter torsion significantly, although the HR augmentations exceeded the difference between diabetics and control 1 patients (p = 0.30). Torsion after inotropic stimulation increased significantly compared with baseline (p = 0.004) and after chronotropic stimulation (p = 0.01) (Fig. 5).

**SLICE POSITION EFFECT.** No significant differences in torsion or circumferential strain were noted among the three adjacent apical slices.

**DISCUSSION**

We report that ventricular maximal torsion during systole and TR-s is increased in type I diabetics with normal ejection fraction, mass, and blood pressure under tight glycemic control. We also observe that this increase in torsion is not accounted for by the higher resting HR found in diabetic patients.

Our findings concur with a recent MRI study by Fonseca et al. (18) that showed increased torsion and systolic torsion rate among patients with type II diabetes with a normal ejection fraction. However, in contrast to our diabetic group, their diabetic patients showed older age, abnormal E/A ratio (100%), LV hypertrophy (100%), poor glycemic control (HbA1c, 9.3 \pm 1.7%), hypertension (68%), and the use of a beta-blocker or calcium channel blocker (22%), rendering it difficult to conclude whether the early changes in torsion are fundamental to the diabetic state or are affected by comorbidities. In our type I diabetic patients under good glycemic control without such comorbidities, we observed that torsion and TR-s still remain elevated, indicating that these features seem to be fundamental to the disease state itself rather than correlated with the comorbidities. Thus, this paradoxical increase in torsion is likely attributable to the presence of diabetes regardless of glycemic control or other factors mentioned above.

We also studied three individuals whose HbA1c levels were \textgreater 7.5%. Their torsion and torsion rates were increased as well, although without statistical significance given a small sample size. The interesting inverse correlation between HbA1c and TR-s (Fig. 4) raises the possibility that the poor glycemic control may modulate this fundamental paradoxical increase in maximal systolic torsion rate. By comparison, the type II diabetes patients with poor control (elevated HbA1c) in the study by Fonseca et al. (18) showed a 20% increase in TR-s, as compared with a somewhat larger 25% increase in our diabetic population.

Fonseca et al. (18) also reported decreased circumferential and longitudinal strains and strain rates among the diabetic patients. In contrast, the preservation of maximal longitudinal, circumferential, and longitudinal strains and strain rates in type I diabetes suggests that the preservation of these features is fundamental to the disease state and not correlated with the comorbidities mentioned above.

**Table 3. HR Effect on Torsion**

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Post-Atropine</th>
<th>Post-Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBP (mm Hg)</td>
<td>128.6 \pm 9.3</td>
<td>130.1 \pm 12.3</td>
<td>147.3 \pm 13.3*†</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>76.0 \pm 10.5</td>
<td>73.0 \pm 14.0</td>
<td>76.3 \pm 8.9</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>66.7 \pm 9.7</td>
<td>88.0 \pm 10.5*</td>
<td>85.7 \pm 10.0*</td>
</tr>
<tr>
<td>Maximal torsion (degree/cm)</td>
<td>1.18 \pm 0.52</td>
<td>1.32 \pm 0.36</td>
<td>1.61 \pm 0.40*†</td>
</tr>
</tbody>
</table>

Data shown as mean values \pm standard deviation. *p < 0.05 compared with baseline. †p < 0.05 compared with post-atropine.

DBP = diastolic blood pressure; HR = heart rate; SBP = systolic blood pressure.

**Figure 4.** Correlation between hemoglobin A1c (HbA1c) and maximal torsion rate during systole (TR-s). Circles = diabetics; line = line fit.
...circumferential strain, and strain rates in well-controlled diabetes patients in our study differed from those of Fonseca et al. (18), which points out a potentially detrimental effect of age, poor glycemic control, hypertension, or the use of beta-blockers or calcium channel blockers on strain and strain rates as early signs of cardiac deterioration. Hypertrophy in particular has been shown to reduce longitudinal strain and strain rates in diabetes independently and incrementally (19). Doppler echocardiography literature showed decreased longitudinal strain and strain rates in diabetics with normal ejection fraction (8–10,19). The patients in these reports also differed from our patient characteristics in that diabetics have mostly type II disease (8–10,19), older age (8–10,19), higher HbA1c levels (8,9,19), and LV hypertrophy (10). Interestingly, only 19% of the diabetics in our study showed the echocardiographic signs of diastolic dysfunction, in contrast to the majority of the diabetics in other studies (8–10,18,19). This predominantly normal diastolic dysfunction could contribute in some manner to the preserved longitudinal shortening and circumferential strain in our diabetics. Alternatively, the increased torsion and systolic torsion rate may represent one of the earliest changes in DCM before the classic signs of diastolic dysfunction manifest in the setting of normal LV ejection fraction.

The comparable end-systolic volume, end-diastolic volume, eccentricity index, and blood pressures between our diabetic and control patients suggest that the changes in inherent myocardial contractility may be responsible for increased torsion in our diabetes patients, rather than differences in loading conditions. Increased torsion has been reported in hypertrophied hearts because of aortic stenosis, for example (20), and additionally in diabetics with LV hypertrophy (18). Inotropic augmentation of torsion and TR-r has been shown previously in human hearts after dobutamine infusion (21). Accordingly, by removing the effects of geometry and loading factors, we speculate that the disturbance in torsion is fundamental to the expression of diabetic pathology in the heart.

Multiple mechanisms have been proposed for DCM, including metabolic disturbances triggered by hyperglycemia, increased free fatty acid oxidation, altered calcium homeostasis, myocyte death, fibrosis, small-vessel diseases, and cardiac autonomic neuropathy (22–28). The paradoxical increase in contractile force could reflect the changes in abnormal fiber structure and function attributable to diabetest via any of these mechanisms. Whether increased torsion represents a fundamental component or an adaptive response in diabetes is also unknown, but the fact that it may be modulated by factors such as hyperglycemia hints at the former and is worth further exploration in animal models. 

**Study limitations.** The early stages of DCM are likely a heterogeneous entity involving multiple mechanisms. Our study was limited in the sample size and not designed to address precise mechanisms or progression of DCM. To eliminate confounding variables, we selected a relatively homogeneous cohort with type I diabetics with tight glycemic control and rigorously obtained ventricular mass and function within normal limits. A prospective cohort study in which our diabetic participants undergo serial MRI studies until torsion is reduced would help define progression of DCM. A similar MRI study involving diabetic cohorts with various levels of HbA1c and their resultant torsion and strain would enhance our understanding of mechanisms and manifestations of DCM.

The patients were considered to have a low probability of coronary artery diseases based on clinical grounds, normal resting TTE, and cine MRI. These criteria do not rule out definitively the possibility of epicardial coronary stenosis. Invasive cardiac catheterization to rule out coronary disease was not obtained because it was not clinically indicated in this population. Stress testing was not performed given the reduced sensitivity and specificity of various modalities in this diabetic population (29). Perfusion defects have been described among asymptomatic diabetics by single–photon emission computed tomography imaging (30,31). The patient populations in these studies were older and obese with multiple comorbidities and higher HbA1c levels. We performed scar imaging in 31% of our diabetics and found no fibrosis. This may reflect the difference in patient characteristics. Also, significant ischemia or necrosis would have resulted in decreased torsion rather than in the increased torsion that we observed, ruling that out as a factor a posteriori.

**Clinical implications.** Diabetic cardiomyopathy is a complex process likely involving multiple mechanisms at the molecular level and affecting myocardial biomechanics. The ability to elucidate the earliest biomechanical changes attributable to DCM would enhance our understanding of the pathogenesis, and eventually allow clinical therapeutic trials aimed at ameliorating heart failure in diabetics. To our knowledge, we have shown for the first time that supranormal torsion and TR-s are characteristic of early asymptomatic type I diabetics with normal ejection fraction, normal mass, and tight glycemic control. In particular, these diabetics manifested predominantly normal diastolic function. The mechanism of systolic enhanced torsion was not related to chronotropic influences of HR known as the “Treppe” effect. This augmented torsion and TR-s may represent a fundamental concomitant of the disease state itself or an adaptation with a cause that is yet to be defined. Regardless, these early responses (increased torsion) differ considerably from the typical late maladaptive features (decreased torsion) manifest in most ischemic or primary cardiomyopathies. Thus, we propose that increased torsion and TR-s may offer a sensitive and early predictive marker of the propensity to cardiac dysfunction in asymptomatic type I diabetic patients, otherwise known as DCM.

**Acknowledgments.** The authors recognize the contributions of Ms. Peggy Brown, Ms. Lynn Coulter, Ms. Katherine A. Lehr, Ms. Kamilla McGhee, Ms. Mary P. Watkins, and Ms. Todd A.
Williams to this project, involving patient recruitment, data collection, cardiac MRI scanning, and echocardiography.

Reprint requests and correspondence: Dr. Samuel A. Wickline, Division of Cardiology, Washington University School of Medicine, Box 8086, 660 South Euclid Avenue, St. Louis, Missouri 63110. E-mail: saw@wuphys.wustl.edu.

REFERENCES