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Assessment of Left Ventricular Function by the Midwall Fractional Shortening/End-Systolic Stress Relation in Human Hypertension

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Objectives. **This study examined left ventricular performance in relatively unselected hypertensive patients by use of physiologically appropriate midwall shortening/end-systolic stress relations.**

Background. **Supranormal left ventricular function has been reported in hypertensive patients, possibly due to an artifact of mismatching endocardial rather than midwall fractional shortening to mean left ventricular end-systolic stress.**

Methods. **Samples of 474 hypertensive patients (150 women, 324 men) and 140 normal subjects (68 women, 72 men) were drawn from a large urban employed population. The inverse relations ($p < 0.0001$) of both echocardiographic endocardial and midwall fractional shortening to end-systolic stress in normal subjects were used to calculate the ratios of observed to predicted endocardial and midwall fractional shortening in hypertensive patients. Midwall shortening was calculated from an elliptic model, taking into account the epicardial migration of the midwall during systole.**

Results. **Use of midwall fractional shortening in hypertensive patients reduced the proportion of patients with function above the 95th percentile of normal from 22% to 4% ($p < 0.0001$) and fractional shortening as a percent of predicted from 107% ($p < 0.001$ vs. 100% in normotensive control subjects) to 95% ($p < 0.0001$; $p < 0.001$ vs. 101% in normotensive control subjects). Midwall shortening was below the 5th percentile of normal in 16% of hypertensive patients instead of 2% with endocardial shortening ($p < 0.0001$): They tended to be older than other hypertensive patients and had concentric left ventricular hypertrophy. Among hypertensive patients, those with concentric left ventricular hypertrophy or remodeling had reduced midwall shortening as a percent of predicted from end-systolic stress ($p < 0.0001$).**

Conclusions. **Use of the physiologically more appropriate midwall shortening/end-systolic stress relation 1) markedly reduces the proportion of hypertensive subjects identified as having high endocardial left ventricular function; and 2) identifies a substantial subgroup of patients with reduced left ventricular function who have concentric geometry of the left ventricle, a pattern associated with high cardiovascular risk.**

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Left ventricular performance is commonly assessed by the deviation of left ventricular chamber shortening from the value predicted for a given level of end-systolic wall stress (1–4). This method provides a measure of left ventricular function that is independent of the influence of myocardial afterload. Although deviations in preload also influence ventricular shortening (5), it appears that end-systolic stress/shortening relations in clinically stable subjects are principally affected by left ventricular contractility. In clinical studies, left ventricular fractional shortening and ejection fraction have been measured at the endocardium, reflecting chamber dynamics but not necessarily providing a direct measure of myocardial fiber shortening (6); in fact, the circumferential fibers responsible for shortening of the left ventricular short axis are located in the midwall between two longitudinal shells responsible for the long-axis shortening and twisting.

Left ventricular performance assessed using the relation of endocardial fractional shortening to wall stress is often reported to be higher in hypertensive patients with or without left ventricular hypertrophy than in normal adults (2–4,7). The relatively high prevalence of increased and the low prevalence of decreased left ventricular function in studies of patients with arterial hypertension may, however, be artifactually influenced by relating endocardial shortening to the average value of end-systolic stress across the thickness of the left ventricular wall.

Recently, Shimuzu et al. (8) confirmed that chamber dynamics may overestimate myocardial function, especially when left ventricular wall thickness is increased and reported depressed systolic midwall shortening in a small group of seven hypertensive patients with left ventricular hypertrophy. There is no information, however, about whether using the physiologically more appropriate midwall approach leads to different conclusions about left ventricular

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function than derived from endocardial fractional shortening in hypertensive patients in population-based studies. Accordingly, we studied midwall left ventricular mechanics in a large sample of normotensive and hypertensive subjects to 1) compare the proportion of hypertensive subjects with supernormal or subnormal left ventricular function identified by either endocardial or midwall measurements; and 2) identify the characteristics of hypertensive patients with depressed left ventricular function by midwall shortening/end-systolic stress relations.

Methods

Subjects. The study group comprised 474 hypertensive (68% male, 41% white, mean age 53 ± 10 years, arterial pressure 152 ± 17/94 ± 11 mm Hg, body mass index 28 ± 4 kg/m^2) and 140 normotensive adults (52% male, 53% white, mean age 44 ± 13 years, arterial pressure 121 ± 10/75 ± 8 mm Hg, body mass index 25 ± 4 kg/m^2, all $p < 0.0001$) drawn from a large employed population in New York that has been previously reported in part (9,10). All subjects were free of evidence of coronary or valvular heart disease or of heart failure by clinical, electrocardiographic and echocardiographic examination and gave informed consent under protocols approved in 1979 and regularly thereafter.

Procedures. Echocardiography was performed the same morning as blood collection and completion of a 24-h urine collection. Arterial blood pressure was measured at the first and fifth Korotkoff phases by arm cuff and mercury manometer, with the subject recumbent at the end of the echocardiographic study.

Laboratory tests. Plasma renin activity was determined by radioimmunoassay, as previously described (11). Serum creatinine and 24-h urinary sodium and potassium in daily excretions were measured using standard analytic technique.

Echocardiography. Two-dimensionally targeted M-mode echocardiograms were recorded on strip chart paper with the subject in a partial left decubitus position. M-mode recordings were performed with the ultrasound beam at or just below the tips of mitral valve leaflets. Strip chart tracings were consecutively coded and interpreted in a blinded manner by two observers. Septal and posterior wall thickness and left ventricular chamber dimensions were measured according to the American Society of Echocardiography and Penn conventions (12,13). Standard methods were used to calculate left ventricular mass and endocardial fractional shortening (fractional shortening) (13–15). Stroke volume was estimated using the Teichholz correction of the cube formula (16) and used to calculate cardiac output and peripheral resistance; left ventricular volumes, stroke volume and cardiac output determined by this method have been shown to be accurate in patients with symmetrically contracting ventricles (17,18). The ratio of stroke index to pulse pressure was used as an indirect measure of arterial compliance (19). Midwall fractional shortening was calculated taking into account the epicardial migration of the midwall during systole, using a model similar to that commonly used to calculate left ventricular mass, which assumes a spherical geometry. Similar to the ellipsoidal model used by Shimuzu et al. (8) to determine the physiologic position of the end-diastolic midwall during systole, constant volumes of the total left ventricular wall and of its inner and outer halves during the cardiac cycle were assumed. Thus,

$$(\text{LVIDd} + \text{Hd})^3 - \text{LVIDd}^3 = (\text{LVIDn} + \text{Hn})^3 - \text{LVIDn}^3, \quad [1]$$

where LVID is ventricular internal dimension; d is end-diastole; H is combined septal and posterior wall thickness; and n is any moment during cardiac cycle. Analogously, the inner ventricular wall shell volume at end-systole can be calculated as follows:

$$(\text{LVIDd} + \text{Hd}/2)^3 - \text{LVIDd}^3 = (\text{LVIDs} + \text{Hs}/2)^3 - \text{LVIDs}^3, \quad [2]$$

where s is systole. From equation 2 the systolic thickness of the inner shell can be calculated, allowing computation of midwall shortening as follows:

$$\frac{(\text{LVIDd} + \text{PWTd}/2 + \text{IVSTd}/2) - (\text{LVIDs} + \text{Hs}/2)}{\text{LVIDd} + \text{PWTd}/2 + \text{IVSTd}/2}, \quad [3]$$

where Hs/2 is the estimated left ventricular inner shell myocardial thickness at end-systole that takes into account the migration toward the epicardium of midwall left ventricular fibers from end-diastole to end-systole; PWTd and IVSd are posterior wall and interventricular septal thicknesses at end-diastole.

Meridional end-systolic stress (ESS) was calculated using cuff systolic blood pressure (SBP) at the end of echocardiographic recordings in the following invasively validated formula (20):

$$\text{ESS} = \frac{0.334 \times \text{SBP} \times \text{LVIDs}}{\text{PWTs} \times \{1 + (\text{PWTs}/\text{LVIDs})\}}. \quad [4]$$

The relation of brachial cuff systolic blood pressure to central end-systolic pressure was previously checked in a separate group of 72 normotensive and 92 hypertensive subjects, with use of a high fidelity, solid state strain gauge transducer functioning as an applanation tonometer to measure simultaneous blood pressure at the dicrotic notch of the carotid pressure waveform, as previously reported (21). The two measurements were closely correlated ($r = 0.91$, brachial systolic blood pressure = 1.21 × notch systolic blood pressure + 7.13, $p < 0.0001$). In the same sample, end-systolic stress values calculated using both brachial and carotid notch blood pressure were even more closely correlated with a near-zero intercept ($r = 0.95$; end-systolic stress [brachial] = 1.26 × end-systolic stress [notch] + 0.81 × 10^3 dynes/cm^2, $p < 0.0001$).

Circumferential end-systolic stress (cESS) was also estimated at the midwall from M-mode tracings, using a cylin-

Table 1. Normal Relations of Endocardial or Midwall Shortening to Estimated Meridional and Circumferential End-Systolic Stress

Relation	Equation	r Value	p Value
Endocardial fractional shortening (eFS) and meridional end-systolic stress (mESS)	$eFS = 92.2 - 31.6 \times \log 10(mESS \times 10^3) \pm 3.6\%$	−0.76	< 0.0001
Endocardial fractional shortening and circumferential end-systolic stress (cESS)	$eFS = 104.3 - 35.1 \times \log 10(cESS \times 10^3) \pm 3.6\%$	−0.83	< 0.0001
Midwall fractional shortening (mFS) and meridional end-systolic stress (mESS)	$mFS = 20.3 - 0.038 \times (mESS \times 10^3) \pm 2.2\%$	−0.33	< 0.007
Midwall fractional shortening and circumferential end-systolic stress (cESS)	$mFS = 20.01 - 0.022 \times (cESS \times 10^3) \pm 2.2\%$	−0.28	< 0.001

dric model (22) previously used for clinical studies (23), in which

$$cESS = \frac{SBP \times (LVIDs/2)^2 \times \left\{1 + \frac{(LVIDs/2 + PWTs)^2}{(LVIDs/2 + PWTs/2)^2}\right\}}{(LVIDs/2 + PWTs)^2 - (LVIDs/2)} \quad [5]$$

Relations of endocardial and midwall fractional shortening to both meridional and circumferential end-systolic stress were therefore examined. To evaluate left ventricular performance independently of end-systolic stress, the ratios between shortening calculated from echocardiographic measurements and those predicted from meridional and circumferential end-systolic stresses were calculated using equations derived from our normal subjects (Table 1).

To evaluate the relation between meridional and circumferential end-systolic stress, these two variables were calculated from two-dimensional echocardiographic measurements in a different sample of 50 normotensive and 50 hypertensive subjects (24). Meridional end-systolic stress was closely related to circumferential end-systolic wall stress calculated at the midwall by an invasively validated method ($r = 0.81$, $p < 0.0001$) (25). Fractional shortening expressed as a percent of the value predicted for calculated end-systolic stress was similar and closely correlated for circumferential and meridional end-systolic stress ($r = 0.72$, $p < 0.0001$).

To take into account the different relations between body size and three-dimensional volumes (such as that of the myocardium) or one-dimensional linear measurements (26), left ventricular chamber dimension was indexed for the first power of height, whereas left ventricular mass was normalized for height to the 2.7 power on the basis of results of a recent multicenter study (27). Traditional normalizations for body surface area are also reported to facilitate comparison with previous reports.

Statistical analysis. Data are expressed as mean value ± SD. The chi-square statistic was used to assess differences of categoric variables between groups. Least-squares linear correlation was used to study univariate relations between variables. Log transformation of both circumferential and meridional end-systolic stress was used in the regression, with endocardial shortening as the best fitting relation, whereas this transformation was not needed in the regression with midwall shortening. One-way analysis of variance with the Dunnett post hoc test was used to compare the subgroups of hypertensive patients with normal, supranormal and low midwall left ventricular function (between, above and below the 95th and 5th percentile of normal in relation to end-systolic stress, respectively) to the normal adults. The Scheffé test was used for post hoc, interhypertensive group comparison. Mean values were adjusted for age by analysis of covariance.

Results

Relations of endocardial and midwall fractional shortening to meridional end-systolic stress. Relations of endocardial fractional shortening to meridional end-systolic stress were significant in both normal subjects ($r = -0.76$, $p < 0.0001$) (Table 1) and hypertensive patients ($r = -0.77$, $p < 0.0001$) (Fig. 1). The relation of midwall fractional shortening to end-systolic stress was also significant in both normal ($r = -0.33$, $p < 0.0001$) and hypertensive groups ($r = -0.26$, $p < 0.0001$) (Fig. 2), but these relations were less strong than those between endocardial fractional shortening and end-systolic stress. This was due in part to the narrower range of midwall than of endocardial fractional shortening values in both normotensive and hypertensive subjects because the degree of scatter of fractional shortening about the regression line was lower for midwall than endocardial fractional shortening in both normotensive subjects (SEE 2.2% vs. 3.6%) and hypertensive patients (2.7% vs. 4.3%). Relations of shortening to circumferential end-systolic stress yielded identical results (Table 1).

The ratios of observed endocardial and midwall fractional shortening to the values predicted for meridional end-systolic stress in normal subjects (expressed as a percent) were calculated in both normal and hypertensive groups. These ratios were 100 ± 10% and 101 ± 12% in the normal subjects for endocardial and midwall shortening, respectively. Ratios of observed to predicted endocardial and midwall fractional shortening in normal subjects followed normal distributions. In the hypertensive group the ratio was significantly increased compared with normal ($p < 0.0001$) for endocardial fractional shortening (107 ± 14%) but significantly reduced ($p < 0.001$) for midwall fractional shortening (95 ± 16%, $p < 0.0001$). The same analysis repeated using

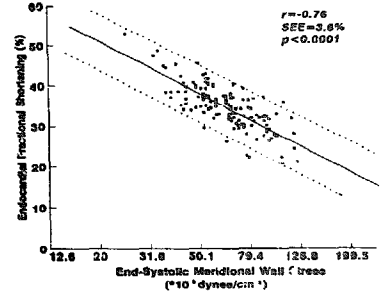

Figure 1. Relations between left ventricular endocardial fractional shortening (**vertical axis**) and meridional end-systolic stress (**horizontal axis**) in normotensive adults (**upper panel**) and hypertensive patients (**lower panel**). Inverse relations are seen in both groups, with data points for a substantial number of hypertensive patients above the upper limit of the 95% confidence interval of the normal relation (**parallel dotted lines**).

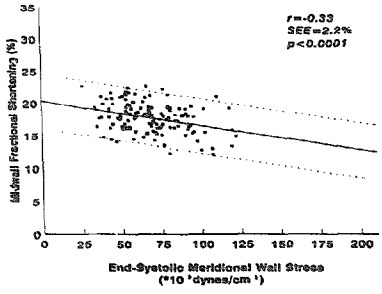

Figure 2. Relation between left ventricular midwall fractional shortening (**vertical axis**) and meridional end-systolic stress (**horizontal axis**) in normotensive adults (**upper panel**) and hypertensive patients (**lower panel**). The inverse relations between midwall fractional shortening and end-systolic stress are statistically significant and exhibit a lower standard error of the estimate than those with endocardial fractional shortening (see Fig. 1). Few data points for hypertensive patients are above the normal 95% confidence interval (between dotted lines), whereas about one-sixth are below the lower limit of the 95% confidence interval.

circumferential end-systolic stress produced identical mean values for the ratio of observed to predicted fractional shortening.

Figure 3 compares the distributions of the ratios of observed to predicted endocardial and midwall fractional shortening in normal subjects and hypertensive patients. As may be seen in the upper panel, the distribution of observed to predicted endocardial fractional shortening was shifted to the right in hypertensive patients, with 22% above the 95th percentile of normal. In contrast, the distribution of observed to predicted midwall fractional shortening of most hypertensive patients closely paralleled that in normal subjects, but a higher proportion of hypertensive patients exhibited low values. Thus, the proportion of hypertensive subjects above the 95th percentile of the normal distribution (with evidence of supranormal left ventricular performance) was statistically lower for observed to predicted midwall shortening than endocardial shortening (5% vs. 22%, $p < 0.001$). Of 91 patients with high left ventricular endocardial shortening, 71 (78%) had normal midwall left ventricular function. Conversely, the proportion of hypertensive subjects below the 5th percentile of the normal subjects increased from 1.5% for endocardial fractional shortening to 16.5% (78 patients) with midwall fractional shortening ($p < 0.001$). Using circumferential stress to calculate observed to predicted shortening ratios identified 79 patients (or 16.7%) as having left ventricular performance below the 5th percentile of normal subjects.

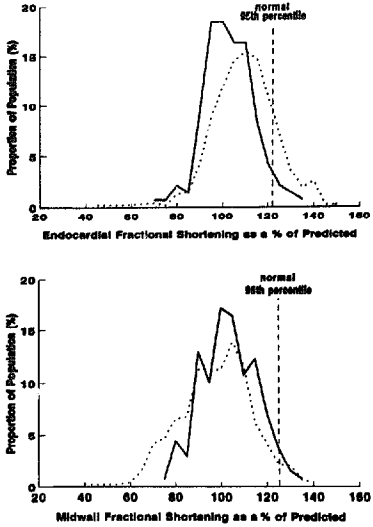

Figure 3. Distribution of the proportion of normotensive subjects **(solid line)** and hypertensive patients **(dotted line) (vertical axes)** who exhibit different levels of the ratio of observed to predicted left ventricular fractional shortening **(horizontal axes). Upper panel,** The distribution of endocardial fractional shortening is shifted toward higher fractional shortening as a percent of predicted in hypertensive patients compared with normal adults. **Lower panel,** The distribution of observed to predicted midwall fractional shortening is generally similar in the normotensive and hypertensive groups, with an increased proportion of hypertensive patients with low values.

Characterization of hypertensive patients with depressed left ventricular performance. The subgroup of 78 hypertensive patients with midwall fractional shortening below the 5th percentile of normal in relation to meridional end-systolic stress had endocardial fractional shortening (32 ± 9%) that was slightly subnormal compared with normal control subjects (35 ± 5%, p = NS) and significantly lower than in hypertensive patients with normal stress/midwall shortening relations (36 ± 6%, $p < 0.0001$). In this group of patients, midwall shortening was depressed (12 ± 2% vs. 18 ± 2% in normal subjects and 17 ± 2% in hypertensive patients with normal stress/midwall shortening relations, both $p < 0.01$). End-systolic meridional and circumferential wall stresses were statistically higher only in patients with supranormal midwall left ventricular performance (86 ± 31 and 171 ± 53 vs. 68 ± 20 and 136 ± 34 × 10^3 dynes/cm^2 in normal subjects $p < 0.01$), whereas no statistical difference from normal or each other was detected in the groups of hypertensive patients with normal (77 ± 25 and 156 ± 44 × 10^3 dynes/cm^2) or low (73 ± 36 and 150 ± 63 × 10^3 dynes/cm^2) midwall performance.

Table 2 shows the general characteristics of hypertensive patients with a midwall shortening/meridional stress relation that revealed low or high left ventricular function compared with both hypertensive patients with normal ventricular function and normal subjects. Patients with reduced left ventricular function tended to be older but did not exhibit even trends toward statistical difference from the other hypertensive subgroups with regard to gender, body size, serum creatinine or plasma renin levels or systolic blood pressure. However, diastolic blood pressure was higher in hypertensive patients with depressed midwall left ventricular performance than in patients exhibiting high left ventricular performance ($p < 0.05$).

Echocardiographic findings in normal subjects and in hypertensive subgroups with normal, high and low midwall

Table 2. Characterization of Hypertensive Patients With Normal Versus Depressed Left Ventricular Performance

		Hypertensive Subjects		
	Normal Subjects (n = 140)	Normal LV Performance (n = 373)	Depressed LV Performance (n = 78)	High LV Performance (n = 23)
Age (yr)	44 ± 13	53 ± 10*	57 ± 9*	50 ± 8*
M/F	72/68	250/123	58/20	16/7
Systolic BP (mm Hg)	121 ± 10	151 ± 17*	156 ± 19*	151 ± 17*
Diastolic BP (mm Hg)	75 ± 8	94 ± 11*	97 ± 11*	92 ± 10*†
Body mass index (kg/m^2)	24.5 ± 4.1	27.9 ± 4.5*	27.6 ± 4.4	27.3 ± 2.3*
Serum creatinine (mg/dl)	1.18 ± 0.24	1.15 ± 0.22	1.23 ± 0.28	1.21 ± 0.23
Plasma renin activity (ng/ml per h)	2.3 ± 2.2	1.9 ± 1.9	1.5 ± 1.7	2.0 ± 2.1
24-h urinary sodium excretion (mmol/day)	119 ± 55	114 ± 65	131 ± 67	114 ± 100
24-h urinary potassium excretion (mmol/day)	45 ± 20	56 ± 24	53 ± 21	65 ± 32*

*$p < 0.01$ versus normal subjects (analysis of variance with Dunnett post hoc test). †$p < 0.05$ versus patients with depressed left ventricular performance (analysis of variance with Dunnett post hoc test). Data presented are mean value ± SD adjusted for age (analysis of covariance) or number of subjects. BP = blood pressure; F = female; LV = left ventricular; M = male.

Table 3. Left Ventricular Geometry and Pump Function in Hypertensive Patients With Normal or Depressed Left Ventricular Performance

		Hypertensive Subjects		
	Normal Subjects (n = 140)	Normal LV Performance (n = 373)	Depressed LV Performance (n = 78)	High LV Performance (n = 23)
Relative wall thickness	0.33 ± 0.06	0.37 ± 0.07*†	0.51 ± 0.10‡	0.28 ± 0.03†‡
LV mass index				
g/m$^{2.7}$	33.4 ± 9.8	45.5 ± 12.1†‡	59.4 ± 21.5‡	39.2 ± 10.0†
g/m^2	76.1 ± 20.1	100.0 ± 24.9†‡	129.1 ± 44.3‡	85.8 ± 18.2†
LV chamber (cm/m)	2.84 ± 0.25	2.96 ± 0.28	2.75 ± 0.33	3.21 ± 0.26‡
Stroke index (ml/beat per m^2)	38.4 ± 7.6	40.9 ± 7.8	30.9 ± 7.0‡	53.6 ± 8.0‡
Cardiac index (liters/min per m^2)	2.52 ± 0.60	2.82 ± 0.6*	2.17 ± 1.51*	3.58 ± 0.72‡
Total peripheral resistance (dynes · s · cm^{-5} · m^2)	3,096 ± 763	3,368 ± 833	4,568 ± 1,283‡	2,586 ± 549*
Stroke index/pulse pressure (ml/mm Hg · m^2)	0.82 ± 0.23	0.76 ± 0.25	0.55 ± 0.17‡	0.95 ± 0.31

*$p < 0.05$ and ‡$p < 0.01$, statistical difference by analysis of variance with the Dunnett post hoc test for comparison with normal subjects. †$p < 0.05$ with Scheffé test versus patients with low left ventricular (LV) performance.

shortening in relation to their end-systolic stress are shown in Table 3. Left ventricular geometry in hypertensive patients with low left ventricular function was characterized by markedly higher left ventricular relative wall thickness and mass than in normal subjects or in the other groups of hypertensive patients (all $p < 0.01$). Cardiac index was reduced, peripheral resistance was markedly elevated, and the stroke index/pulse pressure ratio was lower in patients with reduced midwall function. Groups classified according to observed to predicted midwall shortening using circumferential stress exhibited virtually identical characteristics.

Left ventricular midwall performance in hypertensive patients with different patterns of left ventricular geometry. Among hypertensive patients, 63 exhibited concentric left ventricular hypertrophy (relative wall thickness > 0.45, left ventricular mass index > 50.12 g/m$^{2.7}$ as upper 95% limits of a normal distribution) (Table 3) (27,28). They were compared with the 50 hypertensive subjects with concentric left ventricular remodeling (relative wall thickness > 0.45, normal left ventricular mass index); the 114 with eccentric left ventricular hypertrophy (increased left ventricular mass index, normal relative wall thickness); the 247 patients with normal left ventricular geometry; and the 140 normal subjects. Table 4 shows that endocardial fractional shortening as a percent of predicted was nearly normal in patients with concentric hypertrophy, whereas it was higher in hypertensive patients with normal geometry and eccentric ventricular hypertrophy than in either normal subjects ($p < 0.01$) or hypertensive patients with concentric remodeling or hypertrophy (all $p < 0.0002$). In contrast, midwall fractional shortening as a percent of that predicted for end-systolic stress was statistically lower in patients with concentric left ventricular remodeling or hypertrophy than in normal subjects ($p < 0.01$), whereas the patient groups with normal geometry or eccentric hypertrophy were statistically indistinguishable from normal subjects.

Table 4. Left Ventricular Mechanics in Normal Adults and Hypertensive Patients With Different Geometric Patterns

		Left Ventricular Geometric Pattern in Hypertensive Patients			
	Normal Adults (n = 140)	Normal LV Geometry (n = 247)	Concentric Remodeling (n = 50)	Eccentric Hypertrophy (n = 114)	Concentric Hypertrophy (n = 63)
Age (yr)	44 ± 13	51 ± 10*	55 ± 9*	55 ± 10*	54 ± 9*
LV mass index					
g/m$^{2.7}$	33.4 ± 9.8	38.3 ± 6.8*	41.0 ± 6.9*	60.0 ± 10.8*	66.8 ± 16.6*
g/m^2	76.1 ± 20.1	85.5 ± 15.4†	92.4 ± 16.5*	126.0 ± 22.3*	142.4 ± 38.0*
Relative wall thickness	0.33 ± 0.06	0.35 ± 0.05*	0.50 ± 0.06	0.36 ± 0.05†	0.53 ± 0.08*
Stroke index (ml/m^2)	38.4 ± 7.6	39.4 ± 7.9	32.0 ± 6.3*	47.0 ± 9.3*	35.8 ± 7.2
End-systolic stress (10^3 dynes/cm^2)	68 ± 20	80 ± 24†	55 ± 19*	88 ± 28*	64 ± 32
Endocardial fractional shortening (%)	35 ± 5	36 ± 6	39 ± 7*	35 ± 6	36 ± 9
Midwall fractional shortening (%)	18 ± 4	17 ± 2	15 ± 2†	16 ± 2*	13 ± 2*
Observed/predicted endocardial shortening (%)	100 ± 11	109 ± 12*	103 ± 13	110 ± 14*	98 ± 14
Observed/predicted midwall shortening (%)	101 ± 12	101 ± 13	84 ± 12†	97 ± 13	75 ± 12*

*$p < 0.01$ and †$p < 0.05$, statistical significance by analysis of variance with Dunnett test for comparison with normal subjects.

Discussion

Use of echocardiography to assess left ventricular geometric patterns in hypertensive patients is becoming increasingly common (28). It has been suggested that hypertensive patients undergo a limited two-dimensionally guided M-mode echocardiographic study to assess left ventricular anatomy and function (29). The present study was undertaken to determine the impact of using the physiologically more appropriate midwall left ventricular fractional shortening on the assessment of left ventricular function in human hypertension by echocardiographic stress/shortening relations, taking into account the epicardial migration of the midwall during systole (8).

Effect of using midwall shortening/stress relations on assessment of left ventricular function. Our results indicate that endocardial fractional shortening significantly overestimates left ventricular myocardial performance in hypertensive patients. Endocardial fractional shortening as a percent of the value predicted for a given end-systolic stress in normal adults identified 22% of patients with uncomplicated essential hypertension as having supranormal left ventricular function. Most of these patients, however, were within the normal range when left ventricular midwall mechanics were considered, suggesting that using endocardial instead of midwall shortening in previous studies may have resulted in assessment of left ventricular chamber mechanics, not myocardial performance (2,3,7). Most important, use of the midwall fractional shortening/meridional end-systolic stress relation identified a substantial subgroup (78 of 474, or 16.5%) of hypertensive patients with depressed left ventricular myocardial function. Relations of calculated circumferential end-systolic stress to midwall shortening closely paralleled those with meridional stress, and use of observed to predicted midwall shortening in relation to either measure of stress for identification of patients with depressed left ventricular performance yielded identical results.

The group of patients with relatively lower left ventricular myocardial function exhibited other features associated with high cardiovascular risk in previous studies (30), including concentric left ventricular hypertrophy, higher peripheral resistance and indirect evidence of reduced arterial compliance. Of note, we have recently shown in a nonoverlapping group of normotensive and hypertensive adults that those who had concentric left ventricular hypertrophy had the most elevated ambulatory blood pressure over 24-h, including time spent awake and at home and at work (31).

Our results are consistent with those from the study by Shimuzu et al. (8) who found normal endocardial but depressed midwall shortening in seven hypertensive patients with concentric hypertrophy; they suggested that studies on left ventricular function in hypertension should be reinterpreted according to midwall methods. It is likely that reanalysis of previous echocardiographic studies of patients with concentric hypertrophy would reveal greater depression of left ventricular myocardial function than initially reported (4,32).

Clinical implications. Echocardiographic determination of midwall left ventricular mechanics in hypertensive patients provides a method to study ventricular function in unselected patients without the potential artifact introduced by estimation of left ventricular muscle shortening from motion of the endocardial surface. Determination of midwall left ventricular function also identifies an appreciable proportion of patients with uncomplicated hypertension who exhibit frankly reduced left ventricular myocardial performance, associated with other markers of a high risk state and reveals evidence of diminished systolic myocardial performance in hypertensive patients with the geometric adaptations of concentric left ventricular hypertrophy or remodeling.

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