Tissue Doppler Imaging Consistently Detects Myocardial Abnormalities in Patients With Hypertrophic Cardiomyopathy and Provides a Novel Means for an Early Diagnosis Before and Independently of Hypertrophy

Sherif F. Nagueh, MD; Linda L. Bachinski, PhD; Denise Meyer, MT; Rita Hill, RN; William A. Zoghbi, MD; James W. Tam, MD; Miguel A. Quiñones, MD; Robert Roberts, MD; A.J. Marian, MD

Background—Left ventricular hypertrophy (LVH), the clinical hallmark of familial hypertrophic cardiomyopathy (FHCM), is absent in a significant number of subjects with causal mutations. In transgenic rabbits that fully recapitulate the FHCM phenotype, reduced myocardial tissue Doppler (TD) velocities accurately identified the mutant rabbits, even in the absence of LVH. We tested whether humans with FHCM also consistently showed reduced myocardial TD velocities, irrespective of LVH.

Methods and Results—We performed 2D and Doppler echocardiography and TD imaging in 30 subjects with FHCM, 13 subjects who were positive for various mutations but did not have LVH, and 30 age- and sex-matched controls (all adults; 77% women). LV wall thickness and mass were significantly greater in FHCM subjects ($P<0.01$ versus those without LVH and controls). There were no significant differences in 2D echocardiographic, mitral, and pulmonary venous flow indices between mutation-positives without LVH and controls. In contrast, systolic and early diastolic TD velocities were significantly lower in both mutation-positives without LVH and in FHCM patients than in controls ($P<0.001$). Reduced TD velocities had a sensitivity of 100% and a specificity of 93% for identifying mutation-positives without LVH.

Conclusions—Myocardial contraction and relaxation velocities, detected by TD imaging, are reduced in FHCM, including in those without LVH. Before and independently of LVH, TD imaging is an accurate and sensitive method for identifying subjects who are positive for FHCM mutations.

Key Words: cardiomyopathy ■ genetics ■ hypertrophy ■ systole ■ diastole

Familial hypertrophic cardiomyopathy (FHCM), the most common cause of sudden cardiac death in the young,1 is an autosomal-dominant disease caused by mutations in sarcomeric proteins.2 FHCM is diagnosed clinically by the presence of unexplained left ventricular hypertrophy (LVH), which is conventionally detected by echocardiography. LVH, however, is neither a sensitive nor an early marker for FHCM. Because of variable penetrance,2 LVH is absent in a significant number of mutation-positives until later in life, such as most patients with FHCM due to myosin-binding protein C mutations.3 Similarly, individuals with FHCM due to mutations in cardiac troponin T exhibit minimal LVH, despite having a high incidence of sudden death.2 An alternative approach to the early diagnosis of FHCM is genetic testing, which could identify mutation-positives independently of and before the development of LVH. However, genetic testing is compounded by extensive allelic and nonallelic heterogeneity,2 which restricts the availability of a rapid and convenient assay.

Experimental data strongly indicate the primary abnormality in FHCM is impaired myocardial function, which provides the impetus for the development of compensatory LVH.2 Accordingly, myocardial contraction and relaxation would be expected to be impaired in the absence of LVH. In transgenic rabbits that fully recapitulate the human FHCM phenotype,2 myocardial contraction and relaxation velocities, as detected by tissue Doppler imaging (TDI), were consistently reduced before and independently of LVH. Therefore, we sought to determine in a systematic study whether humans with FHCM, despite a normal LV ejection fraction (LVEF), exhibit reduced myocardial velocities and whether, using TDI, we could identify mutation-positives, irrespective of LVH.

Methods

Study Population

Our Institutional Review Board approved the study, and patients provided informed consent. The study population was composed of...
by guest on April 13, 2017 http://circ.ahajournals.org/ Downloaded from

Individual data points for the lateral Sa and Ea velocities (A) and septal Sa and Ea velocities (B) of the study population.

Statistical Analysis

Variables were compared among the 3 groups by ANOVA, and the Bonferroni t test was used for pairwise multiple comparisons. Statistical significance was defined by P≤0.05.

The mean age and sex of the 3 groups were similar (Table 1). All patients had 2D and Doppler studies satisfactory for analysis.

The mutations in the 13 individuals without any evidence of a phenotype, including LVH, were V606M (4 subjects) and R719W (1 subject) for β-myosin heavy chain, R92Q for cardiac troponin T (1 subject), and InsG791 for myosin-binding protein C (7 subjects). None of the 13 mutation-positive individuals or 30 controls had LVH on ECG or echocardiography. In contrast, 26 of the 30 FHCM patients (87%) with LVH on echocardiography also had LVH on ECG.

2D and Doppler Indices

Septal and posterior wall thicknesses, LV mass, and left atrial volume were increased in FHCM patients compared with normal controls (Table 1). FHCM patients had a significantly lower E/A ratio, longer isovolumic relaxation time, a larger atrial filling fraction, and isovolumic relaxation time were measured from mitral inflow velocities. The peak, duration, and time-velocity integral of pulmonary venous flow velocities were determined. Pulmonary venous flow systolic filling fraction was computed as the systolic/to total forward time-velocity integral. The difference between the duration of atrial reversal and that of the transmitral A wave was calculated as atrial reversal minus mitral A duration.

TDI was applied in the pulse-Doppler mode to allow for a spectral display and recording of mitral annulus velocities at septal and lateral corners. Systolic (Sa), early diastolic (Ea), and late diastolic (Aa) TD velocities were measured, and the Ea/Aa ratio and the dimensionless parameter E/Ea were computed at both corners of the mitral annulus. The E/Ea index corrects for the influence of LV relaxation on mitral peak E velocity and provides a good estimate of LV filling pressures in FHCM patients.

The mean age and sex of the 3 groups were similar (Table 1). All patients had 2D and Doppler studies satisfactory for analysis.

The mutations in the 13 individuals without any evidence of a phenotype, including LVH, were V606M (4 subjects) and R719W (1 subject) for β-myosin heavy chain, R92Q for cardiac troponin T (1 subject), and InsG791 for myosin-binding protein C (7 subjects). None of the 13 mutation-positive individuals or 30 controls had LVH on ECG or echocardiography. In contrast, 26 of the 30 FHCM patients (87%) with LVH on echocardiograms also had LVH on ECG.

2D and Doppler Indices

Septal and posterior wall thicknesses, LV mass, and left atrial volume were increased in FHCM patients compared with mutation-positives without LVH and controls (Table 1). FHCM patients had a significantly lower E/A ratio, longer isovolumic relaxation time, a larger atrial filling fraction, and isovolumic relaxation time were measured from mitral inflow velocities. The peak, duration, and time-velocity integral of pulmonary venous flow velocities were determined. Pulmonary venous flow systolic filling fraction was computed as the systolic/to total forward time-velocity integral. The difference between the duration of atrial reversal and that of the transmitral A wave was calculated as atrial reversal minus mitral A duration.

TDI was applied in the pulse-Doppler mode to allow for a spectral display and recording of mitral annulus velocities at septal and lateral corners. Systolic (Sa), early diastolic (Ea), and late diastolic (Aa) TD velocities were measured, and the Ea/Aa ratio and the dimensionless parameter E/Ea were computed at both corners of the mitral annulus. The E/Ea index corrects for the influence of LV relaxation on mitral peak E velocity and provides a good estimate of LV filling pressures in FHCM patients.

The mean age and sex of the 3 groups were similar (Table 1). All patients had 2D and Doppler studies satisfactory for analysis.

The mutations in the 13 individuals without any evidence of a phenotype, including LVH, were V606M (4 subjects) and R719W (1 subject) for β-myosin heavy chain, R92Q for cardiac troponin T (1 subject), and InsG791 for myosin-binding protein C (7 subjects). None of the 13 mutation-positive individuals or 30 controls had LVH on ECG or echocardiography. In contrast, 26 of the 30 FHCM patients (87%) with LVH on echocardiograms also had LVH on ECG.

2D and Doppler Indices

Septal and posterior wall thicknesses, LV mass, and left atrial volume were increased in FHCM patients compared with mutation-positives without LVH and controls (Table 1). FHCM patients had a significantly lower E/A ratio, longer isovolumic relaxation time, a larger atrial filling fraction, and isovolumic relaxation time were measured from mitral inflow velocities. The peak, duration, and time-velocity integral of pulmonary venous flow velocities were determined. Pulmonary venous flow systolic filling fraction was computed as the systolic/to total forward time-velocity integral. The difference between the duration of atrial reversal and that of the transmitral A wave was calculated as atrial reversal minus mitral A duration.

TDI was applied in the pulse-Doppler mode to allow for a spectral display and recording of mitral annulus velocities at septal and lateral corners. Systolic (Sa), early diastolic (Ea), and late diastolic (Aa) TD velocities were measured, and the Ea/Aa ratio and the dimensionless parameter E/Ea were computed at both corners of the mitral annulus. The E/Ea index corrects for the influence of LV relaxation on mitral peak E velocity and provides a good estimate of LV filling pressures in FHCM patients.

The mean age and sex of the 3 groups were similar (Table 1). All patients had 2D and Doppler studies satisfactory for analysis.

The mutations in the 13 individuals without any evidence of a phenotype, including LVH, were V606M (4 subjects) and R719W (1 subject) for β-myosin heavy chain, R92Q for cardiac troponin T (1 subject), and InsG791 for myosin-binding protein C (7 subjects). None of the 13 mutation-positive individuals or 30 controls had LVH on ECG or echocardiography. In contrast, 26 of the 30 FHCM patients (87%) with LVH on echocardiograms also had LVH on ECG.

2D and Doppler Indices

Septal and posterior wall thicknesses, LV mass, and left atrial volume were increased in FHCM patients compared with mutation-positives without LVH and controls (Table 1). FHCM patients had a significantly lower E/A ratio, longer isovolumic relaxation time, a larger atrial filling fraction, and isovolumic relaxation time were measured from mitral inflow velocities. The peak, duration, and time-velocity integral of pulmonary venous flow velocities were determined. Pulmonary venous flow systolic filling fraction was computed as the systolic/to total forward time-velocity integral. The difference between the duration of atrial reversal and that of the transmitral A wave was calculated as atrial reversal minus mitral A duration.

TDI was applied in the pulse-Doppler mode to allow for a spectral display and recording of mitral annulus velocities at septal and lateral corners. Systolic (Sa), early diastolic (Ea), and late diastolic (Aa) TD velocities were measured, and the Ea/Aa ratio and the dimensionless parameter E/Ea were computed at both corners of the mitral annulus. The E/Ea index corrects for the influence of LV relaxation on mitral peak E velocity and provides a good estimate of LV filling pressures in FHCM patients.

The mean age and sex of the 3 groups were similar (Table 1). All patients had 2D and Doppler studies satisfactory for analysis.

The mutations in the 13 individuals without any evidence of a phenotype, including LVH, were V606M (4 subjects) and R719W (1 subject) for β-myosin heavy chain, R92Q for cardiac troponin T (1 subject), and InsG791 for myosin-binding protein C (7 subjects). None of the 13 mutation-positive individuals or 30 controls had LVH on ECG or echocardiography. In contrast, 26 of the 30 FHCM patients (87%) with LVH on echocardiograms also had LVH on ECG.

2D and Doppler Indices

Septal and posterior wall thicknesses, LV mass, and left atrial volume were increased in FHCM patients compared with mutation-positives without LVH and controls (Table 1). FHCM patients had a significantly lower E/A ratio, longer isovolumic relaxation time, a larger atrial filling fraction, and isovolumic relaxation time were measured from mitral inflow velocities. The peak, duration, and time-velocity integral of pulmonary venous flow velocities were determined. Pulmonary venous flow systolic filling fraction was computed as the systolic/to total forward time-velocity integral. The difference between the duration of atrial reversal and that of the transmitral A wave was calculated as atrial reversal minus mitral A duration.

T
The preserved LVEF in FHCM patients. LVEF is a load-dependent index that does not necessarily reflect the contractile state of the myocardium. The preserved LVEF in FHCM may be the result of decreased afterload due to the small LV cavity.

In summary, irrespective of LVEF, TDI consistently detects myocardial dysfunction in patients with FHCM and in mutation-positive subjects without LVH. TDI can be used to identify mutation-positives before and independently of the development of LVH.

**Acknowledgements**

Supported by a grant from the National Heart, Lung, and Blood Institute, Specialized Centers of Research (PS0-HL42267-01), and a Scientist Development grant (0030235N) from the American Heart Association National Center, Dallas, Texas.

**References**


**TABLE 2. Tissue Doppler Velocities**

<table>
<thead>
<tr>
<th></th>
<th>Normal Subjects</th>
<th>Mutation-Positives Without LVH</th>
<th>FHCM Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Sa, cm/s</td>
<td>15.6±2</td>
<td>8.7±1.7*</td>
<td>6±0.8*</td>
</tr>
<tr>
<td>Lateral Ea, cm/s</td>
<td>16±2.5</td>
<td>9.5±2*</td>
<td>5.9±1.6*</td>
</tr>
<tr>
<td>Lateral Aa, cm/s</td>
<td>9±1.1†</td>
<td>9.8±2.2†</td>
<td>6.8±1.5</td>
</tr>
<tr>
<td>Lateral Ea/Aa</td>
<td>1.8±0.3</td>
<td>0.92±0.3*</td>
<td>0.87±0.2*</td>
</tr>
<tr>
<td>Lateral E/Ea</td>
<td>5.4±1.4</td>
<td>7.99±1.4†</td>
<td>12.7±3.6*</td>
</tr>
<tr>
<td>Septal Sa, cm/s</td>
<td>14.5±1.4</td>
<td>7.96±1.6†</td>
<td>5.7±1*</td>
</tr>
<tr>
<td>Septal Ea, cm/s</td>
<td>15±2</td>
<td>8.5±2.27†</td>
<td>5.3±1.2*</td>
</tr>
<tr>
<td>Septal Aa, cm/s</td>
<td>9.2±1.6†</td>
<td>9.5±2.8†</td>
<td>6±1.6</td>
</tr>
<tr>
<td>Septal Ea/Aa</td>
<td>1.85±0.34</td>
<td>0.98±0.4*</td>
<td>0.92±0.3*</td>
</tr>
<tr>
<td>Septal E/Ea</td>
<td>5.8±0.92</td>
<td>8.65±1.5†</td>
<td>14±3.9*</td>
</tr>
</tbody>
</table>

*P<0.01 vs normal subjects; †P<0.03 vs FHCM patients.
Tissue Doppler Imaging Consistently Detects Myocardial Abnormalities in Patients With Hypertrophic Cardiomyopathy and Provides a Novel Means for an Early Diagnosis Before and Independently of Hypertrophy


Circulation. 2001;104:128-130
doi: 10.1161/01.CIR.104.2.128

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2001 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/104/2/128

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/