Normal Ultrasonic Myocardial Reflectivity in Hypertensive Patients
A Tissue Characterization Study

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Ultrasonic backscatter of myocardial walls is directly related to the morphometrically evaluated collagen content in humans. The integrated backscatter is also increased in hypertrophic cardiomyopathy, whereas it gives normal values in the physiological hypertrophy of elite athletes. We assessed the quantitatively evaluated myocardial reflectivity in 46 mild to moderate, clinically uncomplicated essential hypertensive patients, with echocardiographically assessed normal regional and global left ventricular function, and 22 age- and sex-matched normotensive control subjects. With an echo prototype implemented in our institute, we performed an on-line radiofrequency analysis to obtain quantitative operator-independent measurements of the integrated backscatter signal of the ventricular septum and posterior wall. The integrated values of the radiofrequency signal of myocardial walls were normalized for those of the pericardial interface and expressed as a percent (integrated backscatter index). Hypertensive patients and control subjects differed in mean blood pressure (119±11 versus 95±5 mm Hg, p<0.001) and left ventricular mass index (134±31 versus 105±21 g/m², p<0.001). However, integrated backscatter index overlapped for both the septum (28±17% versus 25±6%, p=NS) and the posterior wall (13±7% versus 13±4%, p=NS). In the hypertensive group, there was no detectable correlation between septal integrated backscatter index and either septal thickness (r=−0.26, p=NS) or mean arterial pressure (r=−0.14, p=NS). Hypertensive patients showed a normal pattern of quantitatively assessed ultrasonic backscatter, even in the presence of left ventricular hypertrophy. This suggests that, in the absence of overt cardiac dysfunction, disproportionate connective tissue growth does not necessarily accompany the compensatory hypertrophic response to arterial hypertension in humans. (Hypertension 1993;21:329–334)

KEY WORDS • hypertrophy • ultrasonics • myocardium • hypertension, essential

Ultrasound tissue characterization consists of the identification and characterization of the abnormalities in the physical or physiological state of biological structures based on analyzing interactions between ultrasound and tissue. This approach has proved accurate with a variety of methods in identifying several cardiovascular disease conditions, including acute myocardial ischemia, infarction, cardiomyopathies, and atherosclerotic plaque. Of all proposed methods, measurement of radiofrequency ultrasound signals (“integrated backscatter”) may permit an objective and reliable assessment of the acoustic properties of myocardium in humans. In myocardial hypertrophy, integrated backscatter has been useful in differentiating between primitive hypertrophic cardiomyopathy, characterized by an abnormally increased wall reflectivity, and hypertrophy of athletes, in which backscatter values fall within the normal range. This different acoustic behavior is thought to reflect different structural and architectural properties of myocardial tissue. In particular, the increased wall reflectivity of hypertrophic cardiomyopathy is probably due to the presence of abnormal myocardial fiber architecture (“disarray”), increased collagen, or both, whereas in athletes the normal reflectivity should mirror the physiological nature of the hypertrophic process, with a proportionate increase in muscle and connective tissue per unit volume of tissue. In fact, in humans a direct correlation exists between the amount of fibrotic tissue and the quantitatively assessed myocardial reflectivity, in full agreement with theoretical and experimental data suggesting that collagen concentration is a primary determinant of myocardial reflectivity.

In this conceptual framework, another target of ultrasonic tissue characterization of great potential interest is hypertensive heart disease. Previous observations concerning the deposition of collagen in pressure-overload hypertrophy have varied. Some authors have found an increase in regional fibrosis, assessed either histologically or biochemically, whereas others have found an increase in total collagen but not in the concentration of collagen in hypertensive left ventricular hypertrophy. The measurement of ultrasound backscatter, which is a robust although technically demanding method for the identification of abnormalities in myocardial composition, therefore appears ideally


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suited for noninvasive assessment of myocardial fibrosis in hypertensive heart.

The purpose of this study was to evaluate the acoustic properties of myocardial tissue, assessed by means of ultrasonic integrated backscatter, in a group of mild to moderate, clinically uncomplicated essential hypertensive patients with variable degrees of left ventricular hypertrophy, as assessed by conventional two-dimensional echocardiography.

Methods

The study population comprised 46 mild to moderate, clinically uncomplicated essential hypertensive patients with echocardiographically assessed normal regional and global left ventricular function. Twenty-two patients were not taking any antihypertensive therapy at the time of the study; 26 were under treatment with antihypertensive agents: angiotensin converting enzyme inhibitors in 14, β-blockers in seven, diuretics in 13, and calcium antagonists in eight. The control group was composed of 22 age- and sex-matched normotensive subjects. Table 1 shows the demographic features of both groups.

Echocardiography

Conventional echocardiographic studies were performed with a 77020A phased array sector scanner (Hewlett-Packard Co., Andover, Mass.) with a 2.5- or 3.5-MHz transducer. Two-dimensional images were obtained in the parasternal long-axis and short-axis views and apical two- and four-chamber views. Left ventricular diameters and wall thicknesses were measured from the two-dimensional targeted M-mode echocardiographic tracings, according to the criteria of the American Society of Echocardiography. Left ventricular percent fractional shortening was calculated as end-diastolic diameter minus end-systolic diameter divided by end-diastolic diameter multiplied by 100. Left ventricular mass was calculated by the Penn convention method and normalized for body surface (left ventricular mass index).

Ultrasonic Tissue Characterization

The quantitative analysis system was developed in our institution and already had been used in a different study population. An SIM 3000 two-dimensional mechanical sector scanner echocardiograph (ESAOTE Biomedica, Genoa, Italy) was used for spatial orientation of the ultrasound beam; quantitative analysis of ultrasonic reflectivity was performed in the regions of interest, i.e., the ventricular septum and the posterior wall of the left ventricle. These regions were visualized in the parasternal long-axis view. The acquisition of the backscattered signal was performed at end diastole, because a systematic variation in backscatter amplitude occurs during the cardiac cycle. A 3.5-MHz frequency transducer (focal distance, 7 cm; −3-dB focal region, 6 cm) was used.

The “native” radiofrequency signal was sampled before the processing chain of the two-dimensional instrument. The radiofrequency signal underwent preamplification, bypassing the receiving circuits of the ultrasonic equipment. The analog signal was fed to an amplifier, and the gain sweep of the amplifier (2–60 dB) was accomplished in 30 steps. This allows the full use of the input dynamic range of the analog-to-digital converter. Sampling was performed by a flash converter with 8 bits of amplitude resolution at a rate of 40 MHz. The digitized signal, from the analog-to-digital converter, was analyzed in real time by a hardware prototype developed in our electronics laboratory. The two-dimensional acquisition gate was visualized on the two-dimensional image so as to ensure its proper positioning.

For analysis of the myocardium, the gate width was kept at 3 μsec, which corresponds to 2.35 mm (for 64 points), given the velocity of ultrasound in biological tissues of 1.57 mm/μsec. This allowed sampling the radiofrequency signal in the subendocardial–middle layers of the myocardium, thus excluding epicardial and endocardial specular reflections. The acquisition gate was placed immediately behind the specular echo of the endocardium (left endocardium for the septum) to minimize the transmural variations in backscatter that are due to the position from which the signal is acquired within the wall. For evaluation of the pericardial echo, a 1.5-μsec gate length was used (which corresponds to 1.2 mm, for 32 points). The acquisition gate was centered on the strongest pericardial reflections, immediately behind the mitral leaflets. The representative value of reflectivity for both myocardial walls and pericardium was calculated as the mean of three measurements.

The hardware analysis involved the measurement of the integrated amplitude of the rectified radiofrequency signal corresponding to the two-dimensional area selected from the echocardiographic image. More analytically, the two-dimensional integrated backscatter index (2D-IB) was calculated over a tissue area, i.e., corresponding to an (n–m) segment in depth and an (r–l) segment in lateral displacement, as follows:

\[
2D-IB = \frac{1}{x_r - x_l} \sum_{j=1}^{r-1} IB(X_j)
\]

where

\[
IB(X_j) = \frac{1}{y_n - y_m} \sum_{i=m}^{n} |S(x_i, y_j)|
\]

represents the processing over the depth of the interrogated tissue; \(S(x_i, y_j)\) is the sequence of the digitized backscattered echoes over the selected two-dimensional area expressed in millivolts.

The system provides a simultaneous display of conventional information together with tissue characteriza-
tion parameters (the 2D-IB alphanumeric index and the lateral displacement profile averaged over the selected depth). Alphanumeric 2D-IB data values are transferred on-line to a personal computer (model AT) for statistical analysis.

Ultrasonic Quantitative Data Analysis

Primary 2D-IB values are highly influenced by interpatient differences in chest morphology, heart structure depth, and ultrasonic impedance. Therefore, to quantitatively assess the reflectivity of the interventricular septum and posterior free wall, we used the percent 2D-IB (as related to the pericardial interface). In particular, 2D-IB results for each heart structure, initially displayed in millivolts, were expressed as percent values, assuming the pericardial interface (from which the peak echo intensity was consistently recorded in each patient) to be 100%. In this manner, the individual pericardial signal strength was used to normalize myocardial signals in each patient, following this procedure: the radiofrequency primary measurement (in millivolts) of myocardial wall (septum or posterior wall) reflectivity divided by the radiofrequency primary measurement (in millivolts) of pericardial reflectivity, the result multiplied by 100, to obtain the percent integrated backscatter index.

Together with the percent 2D-IB, we also displayed the normalized 2D-IB values, expressed in decibels (that is, a relative unit measurement of sound energy, conventionally used), of primary measurements, referred in each subject to the pericardial reflection and calculated as follows: 20 log V/Vr. V and Vr are both primary 2D-IB values and expressed in millivolts. In particular, V is the amplitude value corresponding to the myocardial wall (septum or posterior wall), and Vr is the amplitude value corresponding to the reference pericardial reflection of that subject.

Statistical Analysis

Data are reported as mean±SD. Intergroup differences were tested for significance using the unpaired Student's t test. Relations between radiofrequency and two-dimensional echocardiographic measurements were expressed in terms of linear regression analysis. A value of p<0.05 was considered to be statistically significant.

Results

Demographic characteristics of hypertensive patients and control subjects are shown in Table 1. Arterial blood pressure markedly differed between the two groups. In each subject, the conventional echocardiographic and radiofrequency quantitative ultrasound measurements were obtained.

Echocardiographic Findings

Conventional echocardiographic findings of the two groups are displayed in Table 2. In comparison with normotensive subjects, hypertensive patients showed higher values of left ventricular septal thickness (1.33±0.31 versus 0.95±0.16 cm, p<0.001), posterior wall thickness (1.19±0.23 versus 0.97±0.13 cm, p<0.001), and left ventricular mass index (134±51 versus 105±21 g/m², p<0.001). Hypertensive patients showed a lower value of left ventricular end-diastolic diameter (4.59±0.68 versus 4.90±0.29 cm, p<0.05). Left ventricu-lar hypertrophy was found in 24 hypertensive patients and in none of the control subjects.

Quantitative Analysis of Ultrasound Backscatter

Table 3 shows the values of percent two-dimensional integrated backscatter, as well as normalized data (in decibels) of both the septum and the posterior free wall in hypertensive patients and normal subjects. Similar values of both percent and normalized integrated backscatter in hypertensive patients and the control group were found both in the septum and in the posterior wall (Figure 1). In hypertensive patients, wall thickness was not related to the percent integrated backscatter values for either the septum (r=-0.26, p=NS) or the posterior wall (r=-0.08, p=NS) (Figure 2). In the same way, no significant correlation was found between septal and posterior percent integrated backscatter and mean arterial pressure value (septum, r=-0.14, p=NS; posterior wall, r=-0.02, p=NS).

Hypertrophic hypertensive patients (n=24) were indistinguishable from nonhypertrophic hypertensive patients (n=22) as to value of percent integrated backscatter of both the septum and the posterior wall (Table 4).

Discussion

The population of hypertensive patients in this study showed a definite increase in cardiac mass index compared with age-matched control subjects. These findings are in agreement with those reported in current literature. Several studies have demonstrated that hypertrophy as an adaptive response to excessive loading conditions is an important compensatory mechanism that tends to minimize abnormalities in myocardial stress related to the inciting load. However, hypertrophied muscle may differ from normal muscle in many respects, including the structural composition, with an increase in collagen content that adversely affects mechanical and electrophysiological properties of the myocardium. In the present study, we used an on-line radiofrequency analysis system to obtain quantitative, operator-independent measurements of the acoustic properties of the

| Table 2. Conventional Echocardiographic Data of Control Subjects and Hypertensive Patients |
|----------------------------------------|---------------|---------------|
| Parameter                             | Controls      | Hypertensives |
| Septal end-diastolic thickness (cm)    | 0.95±0.16     | 1.33±0.31*    |
| Posterior wall thickness (cm)          | 0.97±0.13     | 1.19±0.23*    |
| LV end-diastolic diameter (cm)         | 4.90±0.29     | 4.59±0.68†    |
| LV mass index (g/m²)                   | 105±21        | 134±31*       |
| Fractional shortening (%)              | 36±5          | 34±4          |
| LV, left ventricular                   |               |               |

| Table 3. Quantitative Acoustic Data of Control Subjects and Hypertensive Patients |
|----------------------------------------|---------------|---------------|
| Index                                 | Controls      | Hypertensives |
| Septal 2D-IB (%)                       | 25±6±4        | 28±3±16.6     |
| Posterior wall 2D-IB (%)               | 13±4±3        | 12±9±7.2      |
| Septal normalized 2D-IB (dB)           | -12.5±2.2     | -12.0±4.9     |
| Posterior wall normalized 2D-IB (dB)   | -18.6±2.7     | -18.8±4.2     |

2D-IB, two-dimensional integrated backscatter.
myocardium in a population of mild to moderate, clinically uncomplicated hypertensive patients, with and without left ventricular hypertrophy. This technique has been shown to provide reliable quantitative measurements of myocardial acoustic properties in humans. In the present study, we found that hypertensive patients showed a normal pattern of quantitatively assessed ultrasonic backscatter, even in the presence of left ventricular hypertrophy. This suggests that, in the absence of overt cardiac dysfunction, disproportionate connective tissue growth does not necessarily accompany the compensatory hypertrophic response to arterial hypertension in humans.

The studied population consisted of clinically uncomplicated, mild to moderate essential hypertensive patients. We excluded patients with decompensated hypertensive heart disease, because it has already been shown that at the stage of overt cardiomyopathy there is a marked increase in connective tissue content per unit volume of myocardium, inducing a proportional increase in backscatter.

Another peculiarity of this study is that most patients were under antihypertensive treatment. Myocardial structure can be affected differently by various antihypertensive treatments, which show different capabilities to induce the regression of myocardial hypertrophy; furthermore, the latter may asymmetrically affect the fibrous and muscular components of myocardial hypertrophy. This patient selection makes our population even more representative of that encountered in the present clinical practice.

**Biological Basis of Myocardial Acoustic Reflectivity**

The two main potential determinants of alterations in backscatter amplitude are myocardial fiber architecture and abnormal fibrotic tissue accumulation. The well-known diffuse myocardial fiber disarray of hypertrophic cardiomyopathy may play a role in the increased backscatter noted in this condition, as backscatter techniques are sensitive to the anisotropic properties of tissue. The normal backscatter of hypertensive hearts is therefore well in agreement with morphometric studies showing that fiber architecture is generally well maintained despite hypertrophy in the compensated and decompensated pressure-overloaded heart. Regarding fibrosis, ample experimental evidence exists in left ventricular pressure overload indicating that myocardial collagen growth is increased with the hypertrophic process. However, the evidence obtained in humans is substantially less convincing and is related to advanced stages of hypertrophy. In a morphometric autopsy study by Pearlman et al, five hearts with "compensated" arterial hypertension actually had longstanding hypertension, marked left ventricular hypertrophy (with an average mass of approximately 400 g), and, in three cases, even an enlarged heart by chest x-ray. Furthermore, experimental observations regarding collagen deposition in pressure-overload hypertrophy have varied. Some authors have found an increase in regional fibrosis, assessed either histologically or biochemically, whereas others found an increase in total myocardial collagen but not in the concentration of myocardial collagen growth.

**Table 4. Percent Integrated Backscatter of Septum and Posterior Wall in Hypertensive Patients With and Without Left Ventricular Hypertrophy**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Hypertensives with LVH (n=24)</th>
<th>Hypertensives without LVH (n=22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVMI (g/m²)</td>
<td>156±29</td>
<td>112±14*</td>
</tr>
<tr>
<td>Septal 2D-IB (%)</td>
<td>27.3±13.2</td>
<td>29.4±19.9</td>
</tr>
<tr>
<td>Posterior wall 2D-IB (%)</td>
<td>12.8±7.3</td>
<td>13.1±7.2</td>
</tr>
</tbody>
</table>

LVH, left ventricular hypertrophy; LVMI, left ventricular mass index; 2D-IB, two-dimensional integrated backscatter.

\*p<0.001.
collagen in hypertensive left ventricular hypertrophy,16 in particular when arterial hypertension was created by banding the infrarenal abdominal aorta.17

Comparison With Previous Studies

Ultrasonic tissue characterization of hypertensive left ventricular hypertrophy has been attempted with several methods, including texture analysis, cyclic backscatter evaluation, and radiofrequency analysis. Chandrasekaran et al10 differentiated amyloid and hypertrophic cardiomyopathy with the use of computerized quantitative texture analysis of conventional echocardiographic data. However, consistent with our results, they were unable to distinguish patients with left ventricular hypertrophy due to hypertension from normal control subjects. The videodensitometric approach has the advantage of analyzing standard, clinical echocardiograms recorded on videotape. Unfortunately, it also has significant drawbacks, particularly the need for complex, off-line assessment of echocardiographic amplitude data with an additional, time-consuming computing system. Furthermore, the many image-processing manipulations performed when an echocardiogram is recorded (altering gain, time gain compensation, and gray scale mapping functions) may have dramatic and confounding effects on image appearance. Therefore, ultrasound imaging systems were developed based on direct sampling of the total amount of ultrasonic energy returning to the transducer from the target wall. The measurement of the “integrated backscatter” can be expressed either as a cyclic (systolic-to-diastolic) variation or as an amplitude value, either absolute or, as done in this study and by other investigators,22,23 in comparison with pericardial reflection.

Masuyama et al11 showed that the cyclic backscatter variation was reduced in the septum of patients with pressure-overload hypertrophy, as well as in hypertrophic cardiomyopathies, when compared with normal subjects. However, the cyclic backscatter variation seems to provide different information from that of absolute amplitude backscatter measurements. Although the physiological basis of normal cardiac cycle-dependent backscatter variation has not been completely elucidated, it may be related to cardiac contractile performance, the elasticity of myocardial tissue, or contraction-dependent variations in myocardial scatterer geometry.25,26 A different kind of information is provided by ultrasonic backscatter amplitude measurement. This index, which we used in the present study, is mostly related to the structural components of the tissue, first of all to the collagen content. Our results are also consistent with the preliminary data of Angermann et al,24 who found normal or even subnormal values of absolute measurements of myocardial backscatter intensity in hypertensive patients with moderate to severe myocardial hypertrophy. Therefore, our results are congruent with those of Masuyama et al11 and Chandrasekaran et al10 and consistent with the preliminary data of Angermann et al24; they outline a pattern of backscatter response closer to the physiological hypertrophy of athletes6 than to the abnormally increased echodensity found in hypertrophic8 and in dilated9,35 cardiomyopathy.

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