Regional variations of ultrasonic integrated backscatter in normal and myopathic left ventricles

A new multi-view approach

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The purpose of the present study was to determine whether the cyclic variation of integrated backscatter is measurable and quantifiable in all left ventricular walls and whether the information obtained using both parasternal and apical transducer positions can be used to identify changes in myocardial structure and contractility.

The cyclic variation of integrated backscatter was measured from the parasternal long-axis, apical four-chamber and two-chamber views in 26 patients with idiopathic dilated cardiomyopathy (mean age 58 ± 9 years; ejection fraction 29 ± 10%) and compared with information obtained from 30 aged-matched healthy volunteers. For each subject, the cyclic variation of integrated backscatter was calculated from 16 predetermined regions-of-interest located within the myocardium of the basal and mid-segments of the left ventricle imaged from the long-axis view and also the basal mid and apical left ventricular segments imaged from the two apical views. The cyclic variation of integrated backscatter was found to be present in 100% of the analysed regions-of-interest in healthy volunteers and in 87.5% of the analysed regions-of-interest in patients with idiopathic dilated cardiomyopathy. The mean value of cyclic variation of integrated backscatter, averaged from all regions-of-interest in the idiopathic dilated cardiomyopathy group, was significantly reduced compared to that in the healthy volunteers group (32 ± 2.5 dB [mean ± SD] vs 4.8 ± 2.9 dB, P<0.001). Additionally, the healthy volunteers group demonstrated marked regional variability in the magnitude of cyclic variation of integrated backscatter which closely followed the regional changes in the contractile function of the normal heart. These regional differences in the magnitude of the cyclic variation of integrated backscatter were only partially retained in the idiopathic dilated cardiomyopathy group, and suggest that a multi-view approach of the recording of cyclic variation of integrated backscatter can be of value to differentiate normal from myopathic myocardium and to quantify regional differences in myocardial contractile performance throughout the left ventricular walls.

(Key Words: Ultrasound, integrated backscatter, myocardium.)

Introduction

Ultrasonic tissue characterization, based on the measurements of integrated backscatter, has the potential to provide quantitative information which could characterize the functional and structural state of cardiac muscle. Such information is currently not available from the analysis of conventional ultrasonic images. Measurements of integrated backscatter demonstrate a cyclic variation during the cardiac cycle with the maximum value at end-diastole and the minimum value at end-systole. Several clinical studies have shown that the cyclic variation of integrated backscatter is reduced in patients with dilated or hypertrophic cardiomyopathy and that specific changes in the transmural gradient of integrated backscatter can differentiate hypertrophic cardiomyopathy from ventricular hypertrophy due to hypertension. However promising this technique may appear, to date the information has been almost exclusively obtained by parasternal long-axis scanning of the interventricular septum and left ventricular posterior wall. There are few data in the

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literature regarding the use of other standard ultrasound windows (including the apical approach) to record myocardial integrated backscatter levels\textsuperscript{11,12}. In the present study, the cyclic variation of integrated backscatter was determined in patients with idiopathic dilated cardiomyopathy and this information was compared to integrated backscatter levels measured in healthy volunteers. In each case, integrated backscatter levels were recorded from different regions located within all of the left ventricular walls using standard two-dimensional (2D) parasternal long-axis and apical views (four-chamber and two-chamber). The objectives of the study were: (1) to determine whether regional integrated backscatter levels can be measured using apical echocardiographic views in both healthy volunteers and idiopathic dilated cardiomyopathy patients and (2) to compare the integrated backscatter information obtained from the two groups to determine if the changes measured in the idiopathic dilated cardiomyopathy group reflected pathological changes in regional myocardial contractility.

Methods

A prospective study was carried out in which cyclic variation of integrated backscatter measurements obtained from a range of ultrasound imaging positions in idiopathic dilated cardiomyopathy patients were compared with those obtained from healthy volunteers.

Subjects

Cyclic variation of integrated backscatter was measured in a total of 56 subjects: 26 patients with idiopathic dilated cardiomyopathy (Group I), (18 male, mean age 58 ± 9-5 years) and 30 age-matched healthy volunteers (Group II), (19 male, mean age 54 ± 12 years). The clinical criteria for inclusion of idiopathic dilated cardiomyopathy patients into the study were: ejection fraction <50% as assessed by the modified biplane Simpson's method with no evidence of a clear aetiology and no evidence of coronary artery disease on a coronary angiogram. All the healthy volunteers had a negative clinical history, normal physical examination and normal standard echocardiographic examination. Prior to radiofrequency data acquisition, all subjects in both Groups I and II underwent a complete standard M-mode and 2D echocardiographic examination. In order to acquire the radiofrequency data each subject was studied when lying in the left lateral position with images obtained sequentially from both the parasternal and apical transducer positions.

The standard echocardiographic study

Conventional 2D images of the left ventricle were obtained from the parasternal long- and short-axis views and apical four and two-chamber views. Standard chamber dimensions were derived from M-mode echocardiographic images, according to the criteria of the American Society of Echocardiography (ASE)\textsuperscript{13}. The volumes of the left ventricle were measured using the modified biplane Simpson's method.

Acquisition and analysis of radiofrequency data

The real-time 2D echocardiographic integrated backscatter acquisition system used in this study was modified from a commercial Ultrasonic ATL Ultramark 9 (UM9) scanner to allow 2D real-time acquisition of low level radiofrequency data\textsuperscript{14}. A schematic diagram of the system is shown in Fig. 1. Transmit power and time-gain compensation controls on the UM9 were set at preadjusted levels for the study. Once set up, neither the time-gain compensation nor gain controls were altered during the remainder of the study. By triggering radiofrequency image acquisition on the up-stroke of the R-wave of the electrocardiogram (ECG), radiofrequency images were acquired at a rate of six frames per cardiac cycle, at predetermined time-intervals after the occurrence of the R wave. Two cardiac cycles were collected for each scan position. The data acquisition system collected complete radiofrequency sector frames from the UM9 scanner. Digitization was performed at 12 MHz, to 16 bit. Each echo line of radiofrequency data consisted of a maximum of 4096 samples and was dependent on the selected depth of the image. A single image consisted of 128 lines with up to 4096 samples/line and 2 bytes/sample. Thus, each frame occupied 1 MB of storage memory. The radiofrequency acquisition box was equipped with a 16 MB memory board, of which 1 MB was reserved for control registers to allow a maximum of 15 complete frames of radiofrequency data to be acquired. Radiofrequency data were collected from each scan and downloaded to a Sun workstation (SPARC station LX) for signal processing and further analysis. The radiofrequency data were rectified, low pass filtered, log compressed and scan-converted to form an almost visually identical sequence of images to those displayed on the UM9 scanner. Data were obtained from the parasternal long-axis view and from the standard apical four- and two-chamber views. For the analysis purpose, the left ventricle was then divided into 16 standard segments according to the recommendations of the ASE\textsuperscript{13}. Regions-of-interest that encompassed approximately 100 pixels were traced manually within the myocardium avoiding the specular echoes associated with the endocardium and epicardium. The regions-of-interest were placed in the basal and mid-segments of the anteroseptum and posterior wall of the left ventricle in the parasternal long-axis view; within the basal, mid- and apical segments of the septum and lateral wall in the apical four-chamber view and within the basal, mid- and apical segments of the inferior and anterior wall in the two-chamber view (Fig. 2). In nine idiopathic dilated
cardiomyopathy patients and four healthy volunteers, some mid- and apical regions-of-interest included bright specular echoes either because the respective segments of the myocardium were too narrow or there were bright specular echoes within the mid-portion of the myocardium. In these cases, smaller regions-of-interest that encompassed approximately 80 pixels were selected. Using the signal-processing method, integrated backscatter levels were calculated within the selected regions-of-interest from the unprocessed radiofrequency data. For integrated backscatter calculations, values obtained within each scan were referenced to echoes from a standard acoustic grey-scale calibration phantom (Diagnostic Sonar, Livingston, U.K.), imaged at the same gain, transmit power, dynamic-range and time-gain compensation settings, as those employed for each in vivo scan, during radiofrequency data acquisition\(^{15}\). The magnitude of the cyclic variation of integrated backscatter was determined as the difference between maximum and minimum peak values of integrated backscatter during the cardiac cycle, rather than as the difference of the mean values at arbitrarily defined late diastole and late systole\(^{17}\). For each subject, values averaged over two complete cardiac cycles were provided for the quantitative analysis. The calibrated integrated backscatter was calculated as:

\[
\text{IB} = \frac{\int |P(t)|^2 \, dt}{\int |P(t)|^2 \, dt - \int |P(t)|^2 \, dt}
\]
Table 1 Inter-observer and intra-observer variability of integrated backscatter measurements in 15 subjects (six healthy volunteers and nine idiopathic dilated cardiomyopathy patients)

<table>
<thead>
<tr>
<th>Magnitude of CV of IB (dB)</th>
<th>Inter-observer variability</th>
<th>Intra-observer variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAX</td>
<td>0.7 ± 0.5</td>
<td>0.6 ± 0.3</td>
</tr>
<tr>
<td>2C</td>
<td>1.0 ± 0.6</td>
<td>0.9 ± 0.4</td>
</tr>
<tr>
<td>4C</td>
<td>0.9 ± 0.5</td>
<td>0.7 ± 0.3</td>
</tr>
</tbody>
</table>

CV = cyclic variation; IB = integrated backscatter; LAX = long-axis view, 2C = apical two-chamber view; 4C = apical four-chamber view

where \( V(t) \) was the amplitude of the uncompressed radiofrequency signal from the myocardial region of interest, \( P(t) \) the amplitude of the uncompressed radiofrequency signal from the phantom, and \( 2\Delta t \) was the time-gate over the region-of-interest. For the statistical analysis, the mean cyclic variation of integrated backscatter was calculated from all 30 healthy volunteers and 26 idiopathic dilated cardiomyopathy patients.

### Statistical analysis

The significance in the difference between the maximum to minimum value of integrated backscatter during the cardiac cycle was determined using paired Student’s t-test. Inter-group and intra-group differences in the magnitude of cyclic variation of integrated backscatter were tested for significance using one-way analysis of variance, with subgroup analysis by Scheffe’s F test. Differences were considered statistically significant when the probability of error was \( P < 0.05 \). The integrated backscatter values are reported in the text as mean ± standard deviation and in the figures as mean ± standard error in dB.

### Reproducibility

Reproducibility was assessed using the technique described by Bland and Altman[18] in a group of 15 randomly selected subjects (six healthy volunteers and nine idiopathic dilated cardiomyopathy patients). In eight subjects the ultrasonic images were of good quality and seven of moderate to poor quality. Two independent observers determined inter-observer variability by comparison of repeated analysis of the integrated backscatter images obtained from those subjects. Intra-observer variability was estimated by one observer repeating the analysis process a second time after 2 weeks in the same group of subjects. Observer variations in the assessment of the magnitude of cyclic variation of integrated backscatter are presented in Table 1.

The mean absolute differences of the magnitude of cyclic variation of integrated backscatter between the observations were 0.6 ± 0.3 dB for good quality images, 0.8 ± 0.4 dB for moderate to poor images (intra-observer) and 0.8 ± 0.5 dB for good quality images, 0.9 ± 0.5 dB for moderate to poor images (inter-observer).

### Results

Cyclic variation of integrated backscatter in idiopathic dilated cardiomyopathy patients compared to healthy volunteers

The clinical characteristics and the conventional echocardiographic variables of the cohort of 26 idiopathic dilated cardiomyopathy patients and 30 healthy volunteers are listed in Table 2. Standard echocardiographic images taken from the long-axis view were considered of good quality in 21 healthy volunteers and 14 idiopathic dilated cardiomyopathy patients, of average quality in nine healthy volunteers and 10 idiopathic dilated cardiomyopathy patients and of poor quality in two idiopathic dilated cardiomyopathy patients. Using the apical views, good quality images were obtained in 19 healthy volunteers and 11 idiopathic dilated cardiomyopathy patients, average quality images in nine volunteers and 10 idiopathic dilated cardiomyopathy patients and below good quality in two and five respectively. Thus, in the idiopathic dilated cardiomyopathy group, 24/416 left ventricular segments and 19/480 segments in the group of healthy volunteers were considered of inadequate quality for integrated backscatter measurements and were excluded from the analysis. Finally, cyclic variation of integrated backscatter was measured from a total number of 853 regions-of-interest from both study groups and was found to be present in 343/392 (87.5%) regions-of-interest in idiopathic dilated cardiomyopathy patients and in all 461 regions-of-interest in healthy volunteers group. The mean value of cyclic variation of integrated backscatter averaged from all regions-of-interest for each study group separately was significantly smaller in idiopathic dilated cardiomyopathy group than in healthy volunteers group (3.2 ± 2.5 dB vs 4.8 ± 2.9 dB, \( P < 0.0001 \)).

Figure 3 illustrates the mean values of cyclic variation of integrated backscatter averaged for each predetermined region-of-interest within the left ventricle in the 26 idiopathic dilated cardiomyopathy patients and 30 healthy volunteers. In all regions-of-interest within the long-axis view, a significant difference in the mean cyclic variation of integrated backscatter was found between the two study groups. This difference was not preserved in all selected regions-of-interest within the two apical views: a significant decrease in mean cyclic variation of integrated backscatter was observed in nine of the 12 apical regions-of-interest, while the remaining
Table 2  Baseline clinical, two-dimensional and Doppler echocardiographic characteristics of 26 patients with idiopathic dilated cardiomyopathy and 30 healthy volunteers

<table>
<thead>
<tr>
<th></th>
<th>Idiopathic dilated cardiomyopathy patients (n=26)</th>
<th>Healthy volunteers (n=30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>58 ± 9.5</td>
<td>56 ± 8</td>
</tr>
<tr>
<td>Heart rate (beats . min⁻¹)</td>
<td>74 ± 13</td>
<td>67 ± 11</td>
</tr>
<tr>
<td>New York Heart Association Functional Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sinus rhythm</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>130 ± 15</td>
<td>127 ± 13</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>85 ± 11</td>
<td>80 ± 11</td>
</tr>
<tr>
<td>LV ED indexed volume (ml . M⁻²)</td>
<td>102 ± 37</td>
<td>64 ± 11</td>
</tr>
<tr>
<td>LV ES indexed volume (ml . M⁻²)</td>
<td>73 ± 34</td>
<td>27 ± 8</td>
</tr>
<tr>
<td>LV ejection fraction (%)</td>
<td>29 ± 11</td>
<td>60 ± 7</td>
</tr>
<tr>
<td>ED posterior wall thickness (mm)</td>
<td>0.8 ± 0.2</td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>ED septal thickness (mm)</td>
<td>1.0 ± 0.3</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>% systolic thickening</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior wall</td>
<td>39 ± 19</td>
<td>65 ± 13</td>
</tr>
<tr>
<td>Interventricular septum</td>
<td>18 ± 9</td>
<td>35 ± 10</td>
</tr>
<tr>
<td>Isovolumetric relaxation time (ms)</td>
<td>97 ± 46</td>
<td>67 ± 10</td>
</tr>
<tr>
<td>Peak E wave velocity (m . s⁻¹)</td>
<td>0.65 ± 0.18</td>
<td>0.61 ± 0.14</td>
</tr>
<tr>
<td>Peak A wave velocity (m . s⁻¹)</td>
<td>0.6 ± 0.36</td>
<td>0.49 ± 0.17</td>
</tr>
</tbody>
</table>

LV=left ventricle; ED=end-diastolic; ES=end-systolic

three regions-of-interest (located within mid-septum and mid- and apical- inferior wall) demonstrated no difference between the two study groups.

Regional differences of cyclic variation of integrated backscatter in healthy volunteers and in idiopathic dilated cardiomyopathy patients

In the healthy volunteers group a significantly higher magnitude of cyclic variation of integrated backscatter was observed in the basal left ventricular segments compared to mid- and apical segments when imaged from both four-chamber and two-chamber views (Fig. 4(b),(c)). When the data were obtained from the long-axis view no difference was observed in the magnitude of cyclic variation of integrated backscatter between basal and mid-segments of the left ventricle, but a significantly higher value of cyclic variation was found in the regions-of-interest located within the posterior wall when compared to the anteroseptum (Fig. 4(a)). In idiopathic dilated cardiomyopathy patients the basal–inferior segment of the left ventricle demonstrated a higher magnitude of cyclic variation of integrated backscatter compared to the apical–inferior segment, when imaged from the two-chamber view, while no difference was observed between the other left ventricular segments from both apical views. When the echocardiographic imaging was performed from the long-axis view no significant differences were observed between the posterior wall and the anteroseptum (Fig. 4(a),(b),(c)).

Discussion

Cyclic variation of integrated backscatter in idiopathic dilated cardiomyopathy patients compared to healthy volunteers

In this study, we found that cyclic variation in integrated backscatter was present when measured from the 2D long-axis, four-chamber and two-chamber views in 87.5% of analysed regions-of-interest in idiopathic dilated cardiomyopathy patients and within all analysed regions-of-interest in healthy volunteers. Idiopathic dilated cardiomyopathy patients showed significantly reduced mean values of cyclic variation of integrated backscatter in all selected regions-of-interest in the long-axis view and in 3/12 regions-of-interest in the two apical views. The regions-of-interest located within the mid-septum and the mid- and apical–inferior wall did not demonstrate significant differences in the mean cyclic variation of integrated backscatter between the two study groups.
The mechanism for the reduced cardiac cycle-dependent variation of integrated backscatter in idiopathic dilated cardiomyopathy hearts is still not well defined. Several experimental studies have shown that magnitude of cyclic variation of integrated backscatter is dependent on the contractile performance of the myocardium\(^\text{19-21}\). Vered et al. suggested that apart from decreased myocardial contractility, myocardial fibrosis must be an additional determinant of the reduced cycle variation of integrated backscatter in idiopathic dilated cardiomyopathy patients\(^\text{21}\). More recently O'Brien et al. reported that ultrasonic backscatter is directly related to sarcomere length and myocardial thickness and that the changes in their size during the cardiac cycle may be responsible for the cycle variation of integrated backscatter\(^\text{22}\).

In the current study, although idiopathic dilated cardiomyopathy patients had globally hypocontractile left ventricles, the magnitude of cyclic variation of integrated backscatter was not equally reduced in all analysed regions-of-interest. Interestingly, the regions-of-interest located within the mid-septum and mid- and apical-inferior walls did not demonstrate any significant difference when compared to the healthy volunteers group. This finding may be related to the heterogeneous pattern of the histopathological changes of the myocardium in idiopathic dilated cardiomyopathy\(^\text{23}\), but this hypothesis cannot be proved in this study, as none of the idiopathic dilated cardiomyopathy patients underwent endomyocardial biopsy.

When mean cyclic variation was averaged for each study group, from the basal, mid- and apical segments of the left ventricle, significant differences were found between all segments. This was more pronounced in the basal segments than in the mid- and apical ones. These findings are comparable with those obtained by Ota et al. who measured the cyclic variation of integrated backscatter from multiple regions-of-interest in cardiac transplanted patients in order to determine whether the technique can detect acute allograft rejection\(^\text{24}\).

In that study it was suggested that the combination of cyclic variation from multiple regions-of-interest was more sensitive for the diagnosis of cardiac allograft rejection.

\(\text{CV IB}=\text{cyclic variation of integrated backscatter}; \text{dB}=\text{decibels.} \)
Regional differences of cyclic variation of integrated backscatter observed in healthy volunteers and in idiopathic dilated cardiomyopathy patients

The healthy volunteers group demonstrated marked regional variability in the magnitude of cyclic variation of integrated backscatter throughout the left ventricular walls. In contrast, the idiopathic dilated cardiomyopathy group showed very little regional variability. These regional differences in the healthy volunteers group may be related to the regional differences in the contractile performance of the left ventricle reported in several clinical studies[25-27]. According to the functional anatomy of the left ventricle, during cardiac systole the contraction of longitudinal oriented fibres contribute to long-axis shortening, while the contraction of circumferential fibres contribute to a reduction in the short-axis of the left ventricle[27]. Long-axis shortening of the left ventricle is most prominent in the base of the heart, while the apex remains effectively fixed[26]. In addition, the contraction of the circumferential oriented myocardial fibres is most vigorous in the posterior wall compared to the remainder of the left ventricular walls[27]. When data were acquired from the parasternal long-axis view, the measured changes in cyclic variation of integrated backscatter closely paralleled the observed changes in the systolic thickening of the circumferential oriented fibres, while in the two apical views the changes in the magnitude of cyclic variation of integrated backscatter corresponded to systolic segmental shortening of the longitudinal oriented myocardial fibres. In idiopathic dilated cardiomyopathy patients the regional changes in the magnitude of cyclic variation were decreased or absent possibly because of a combination of the distortion of the myocardial fibres and the impaired contractile function of the cardiac muscle. These findings are compatible with the results of previous experimental studies which showed that regional and intramural differences in the magnitude of cyclic variation of integrated backscatter throughout the left ventricular walls are related to the respective regional and intramural
differences in the contractile performance of the left ventricle[19,20,29].

These results present a possible correlation between regional contractile performance and regional cyclic variation of integrated backscatter, although this does not imply that changes in the amplitude of backscatter reflect changes in contractility per se. This approach will derive the relative and not the absolute values of the peak cyclic variation of integrated backscatter because of the varying angle of incidence for basal, mid- and apical segments in parasternal and apical views[30]. In this study we have shown that cyclic variation of integrated backscatter was present throughout the left ventricular walls, when imaged not only from the long-axis but also from apical four-chamber and two-chamber views, in both idiopathic dilated cardiomyopathy and healthy volunteers groups. In the idiopathic dilated cardiomyopathy group, although some regions-of-interest did not show a significant difference in the magnitude of cyclic variation of integrated backscatter compared to the healthy volunteers group, the mean cyclic variation of integrated backscatter averaged from multiple regions-of-interest was significantly reduced throughout the left ventricle. Furthermore, the healthy volunteers group demonstrated marked regional variability in the magnitude of cyclic variation of integrated backscatter with the maximum values occurring at the basal segments and the minimum at the mid and apical segment when imaged from the apical view. When data were acquired from the parasternal long-axis view, the maximum values of the cyclic variation of integrated backscatter occurred at the segment located in the posterior wall and the minimum at the segments located within the anteroseptum. These regional differences in the magnitude of the cyclic variation of integrated backscatter closely followed the regional differences in the contractile function of the normal heart. In contrast, the idiopathic dilated cardiomyopathy group demonstrated very little regional variability in the magnitude of the cyclic variation of integrated backscatter throughout the left ventricular walls.

These data suggest that a multi-view approach to the recording of cyclic variation of integrated backscatter may be used to differentiate normal from myopathic myocardium and may quantify regional differences in myocardial contractile performance.

**Technical limitations**

Our results may have been influenced by the following technical limitations.

The conventional echocardiographic images were of poor quality in 7/56 subjects (five dilated cardiomyopathy patients and two healthy volunteers) and thus integrated backscatter measurements could not be made from all left ventricular segments in these subjects. Thick bright echoes were present within the myocardium of the septum and inferior wall when imaged from the two apical views in seven idiopathic dilated cardiomyopathy patients and three healthy volunteers. These bright echoes might have influenced the magnitude of cyclic variation of integrated backscatter by coming into the ultrasound beam only in systole or in diastole as a result of the heart motion during the cardiac cycle, relative to the ultrasound beam[13]. Such echoes have been also noticed by other investigators, mainly within the septum[7,8,17].

Furthermore, despite the fact that good inter- and intra-observer variability was obtained the mean values of cyclic variation of integrated backscatter exhibited relatively large standard deviation. Such standard deviation may be attributed to the fact that echocardiographic images were not acquired in mutually parallel or perpendicular orientations but were obtained at somewhat arbitrary angles, dictated by the intercostal spaces and other aspects of thoracic anatomy.

As has been previously reported, the magnitude of cyclic variation of integrated backscatter is related to the angle between orientation of the predominant myocardial fibres and the ultrasound beam[30]. Thus, when measuring the differences of the magnitude of cyclic variation of integrated backscatter between the segments of the left ventricle, correction for the predominant fibre orientation should be taken into account. A potential source of error in our study was also the limited number of frames acquired for each cardiac cycle. As a consequence, end-systolic and end-diastolic frames could have been measured in slightly different time periods of the cardiac cycle. To minimize this effect, the minimum and the maximum magnitude of the integrated backscatter was taken to assess the magnitude of the integrated backscatter cyclic variation[17].

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**References**


