Usefulness of a New Sound Spectral Averaging Technique to Distinguish an Innocent Systolic Murmur from That of Aortic Stenosis

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We present a new method to record and display heart sounds that uses a hand-held computer and stethoscopic recording device. It allows for rapid spectral and waveform displays of murmurs and provides a means for signal averaging of spectral frequency content. Compared with aortic stenosis, innocent murmurs primarily contain frequencies of <300 Hz and persist for a shorter duration at the upper-frequency levels. This method provides for rapid characterization of innocent murmurs, a means for comparison with other murmurs, and transmission of acoustic data to distant sites. ©2005 by Excerpta Medica Inc.

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With the advent of high-fidelity digital stethoscopy and inexpensive software for computer analysis, tools are now available to record and analyze cardiovascular sounds quickly and accurately. Accordingly, we have designed a method that uses modern technologic means to characterize innocent precordial murmurs and provides a way to differentiate these murmurs from those caused by abnormal conditions.

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Study patients, who voluntarily gave informed consent according to the guidelines approved by the institutional review board of St Vincent's Hospital, Indianapolis, Indiana, had been referred to the cardiology center to undergo 2-dimensional (2-D) echocardiographic examination combined with a Doppler study. In the instance of the innocent murmurs, primary physicians had requested this examination for the purpose of evaluating a "heart murmur."

Sound recordings were obtained from subjects found to have an ultrasound examination in which all cardiac chambers and valves were observed to be normal and abnormal Doppler findings were absent.[1] These patients were compared with another group found to have valvular aortic stenosis, which formed the basis for another study reported elsewhere.[2] In this latter study, peak and mean transvalvar aortic pressure gradients were estimated through cardiac Doppler study, utilizing the modified Bernoulli equation. In all cases, peak velocities across the aortic valve were >1.9 m/s, and all 2-D images disclosed anatomic deformities with restricted opening of the aortic valves.

All recordings were obtained by 1 of us (MET) from the location of maximum auditory transmission, usually from the middle or upper left sternal border. At that time, careful auscultation was performed to confirm sound characteristics consistent with an innocent murmur. Doppler findings considered normal included the absence of intracardiac flow abnormalities and the presence of no more than trace amounts of regurgitation across any of the valves. The sound recording for each subject required about 3 minutes and was performed in a quiet room. Subsequent transfer to a standard computer and the signal processing and analysis required about 10 minutes.

The results in this normal population were compared with sounds previously recorded in an original group of 41subjects with aortic stenosis that was later augmented to 47 subjects. This latter group formed the basis for a separate study in which the spectral sound patterns were used to assess the severity of the stenosis.[2]

Stethoscopes used to record the sounds were models DR 200 (table top model) and DR 300 and ProSteth (hand-held models) manufactured by Point of Care Diagnostics, Inc. (Toronto, Ontario, Canada). The sounds were obtained digitally and transferred to a laptop computer (Inspiron, model 7500, Dell Computer Corp., Round Rock, Texas.) and subsequently analyzed with the SoundsEasy software provided by Point of Care.

The sounds were first plotted in spectral and waveform displays (Figure 1). The waveform display was band-pass filtered digitally at 125 to 500 Hz to facilitate recognition of individual components (sounds and murmurs) of the cardiac cycle. These cardiac cycles were visually inspected for quality, and those free of artifacts were highlighted. We found that optimal recognition of the murmur boundaries was achieved when the sound spectrograph was color-coded with red representing all intensities >−25 dB, and black, intensities below this level. We arbitrarily selected this sound intensity threshold as the point at which murmurs are no longer registered, for this seemed to provide the clearest picture of murmurs while minimizing background noise.

An average murmur was computed from those selected (Figure 1), and the intervals during which the spectral intensity remained above >−25 dB (i.e., red at 150, 200, 250, and 300 Hz) were measured. The best separation between the innocent and pathologic murmurs was provided by the durations at 200 Hz. Thus, only this latter level was used in the results.

For statistical comparisons, we used the standard *t* test for independent groups.

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Innocent murmurs were identified in 62 subjects (average age 33 ± 17 years; range 4 to 77) who were compared with a group with known valvular aortic stenosis (average age 66 ± 15 years; range 7 to 89). Table 1 lists the general characteristics of the 2 groups. Although the average age of those with innocent murmurs was less, older patients (>40 years) showed no significant difference in murmur characteristics from their younger counterparts.

As noted in Table 1, peak frequencies in the aortic stenosis group were significantly higher than those of the innocent murmur group. Only 1 patient (2%) with aortic stenosis had a peak frequency <200 Hz. This patient had mild stenosis, with an estimated peak valve gradient of 23 mm Hg; thus, all other patients (98%) with mild or severe stenosis demonstrated frequencies >200 Hz. In contrast, 28 subjects (45%) of the group with innocent murmurs failed to reach 200 Hz. When the patients from each group with peak frequencies >200 Hz were compared, murmur durations >200 Hz were significantly longer for the aortic stenosis group. No innocent murmurs were >160 ms at this level. Thirteen patients with aortic stenosis also had durations of <160 ms. This group manifested less severe stenosis, with an average peak pressure gradient of 35 (range 15 to 46). In contrast, the severity of stenosis was greater in the group with durations >160 ms, with an average peak pressure gradient within this latter group of 70 mm Hg (range 15 to 185).

Figures 2 and 3 demonstrate the effect of combining the duration at >200 Hz with the peak frequency: When all cases of aortic stenosis are included, considerable overlap is noted between the 2 groups (Figure 2) ; however, when only cases with significant grades of stenosis are included (peak gradient >50 mm Hg), then separation between the groups is virtually complete (Figure 3).

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Previous studies have demonstrated that sound energy density and turbulence energy density are higher in the murmur of aortic stenosis than in innocent murmurs.[3] The turbulence energy density is related to the peak blood velocity, which is high in aortic stenosis and contains high frequencies with higher energy.[4] Nevertheless, innocent precordial murmurs and those of aortic stenosis are both likely produced by proximal aortic flow sufficiently rapid to produce turbulence.[5,6]

Spectral analysis of murmurs of aortic stenosis can be used to assess the severity of this condition. Disease severity correlates not only with the proportion of high-frequency waves[7,8] but also with the duration that these latter waves persist.[2]

Although our study included many older subjects (>40 years of age) with innocent murmurs, we did not include those with aortic valve "sclerosis," that is, thickened leaflets without abnormally high transvalvar Doppler-derived velocities. Patients with mildly elevated velocities were included in the group with aortic stenosis, but as noted from this and a previous study from our laboratory,[2] these patients can usually be differentiated from those with severe stenosis by time–frequency analysis.

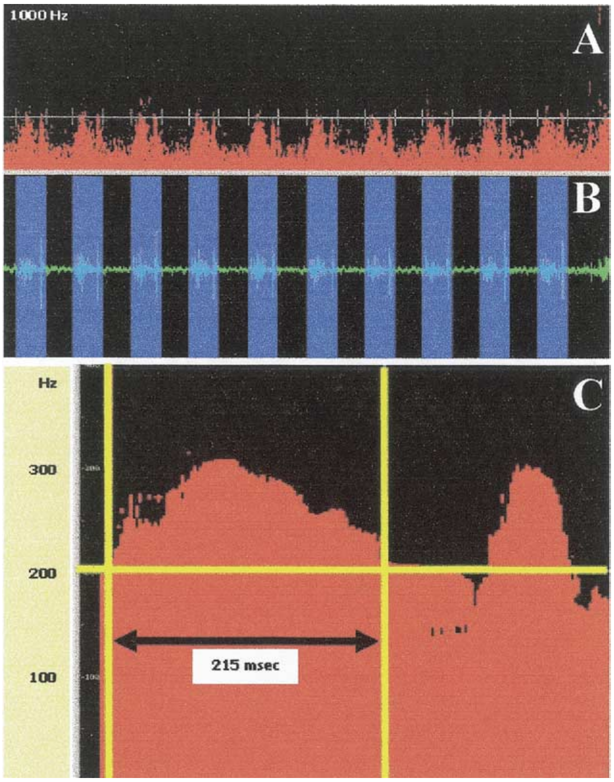

FIGURE 1. *(A)* **Murmur frequency spectra. The *red* areas represent the most intense frequency components. Attenuation of sound intensity by >25 dB results in alteration to *black*. The *horizontal bar* is manually placed at the representative peaks of the murmurs as determined visually, and peak frequency (Hertz) is determined from a vertical scale (not shown).** ***(B)*** **Same sounds, filtered and displayed in waveform format. After a single representative area is selected manually, the highlighted areas result from computer selection of corresponding areas of all cycles, and they are averaged into 1 composite cycle.** ***(C)*** **From the resultant sound complex, time intervals can be measured. The *horizontal bar* is placed at the 200-Hz frequency level (registered numerically at the left). The *vertical bars* are placed at the beginning and end of the murmur at this level, and the time duration *(215 ms)* is also rendered automatically.**

We also did not include subjects with systolic ejection murmurs resulting from high flow states, as might be encountered with fever, anemia, and so forth, conditions that conceivably could elevate peak frequency in the absence of prolonged murmur duration. We did not systematically study the systolic murmurs caused by other conditions, such as ventricular septal defect, mitral regurgitation, and hypertrophic subaortic stenosis. We have noted, however, that these conditions usually generate murmurs with frequencies that are higher in frequency and longer in duration than those of the innocent variety.

Although expert clinicians can usually estimate the likelihood of significant valvular aortic stenosis or other abnormal conditions from auscultation alone, this method should add objectivity to this examination and provide support for inexperienced or general physicians. We believe that the application of this approach would be useful in screening patients with systolic murmurs before considering more costly echo/Doppler and other studies.

The results of this study suggest that a 2-step ap-

TABLE 1 General Characteristics of All Cases

Precordial Murmur	Study Population			Peak Frequency (Hz)		No. of Cases >200 Hz	Duration (ms) at 200 Hz	
	Men	Women	Total	Mean ± SD	Range		Mean ± SD	Range
Innocent	17	45	62	215 ± 50*	120–330	34*	95 ± 35*	25–160
Aortic stenosis	25	22	47	330 ± 80*	180–560	46*	175 ± 48*	40–270

*Difference between groups significant (p <0.005).

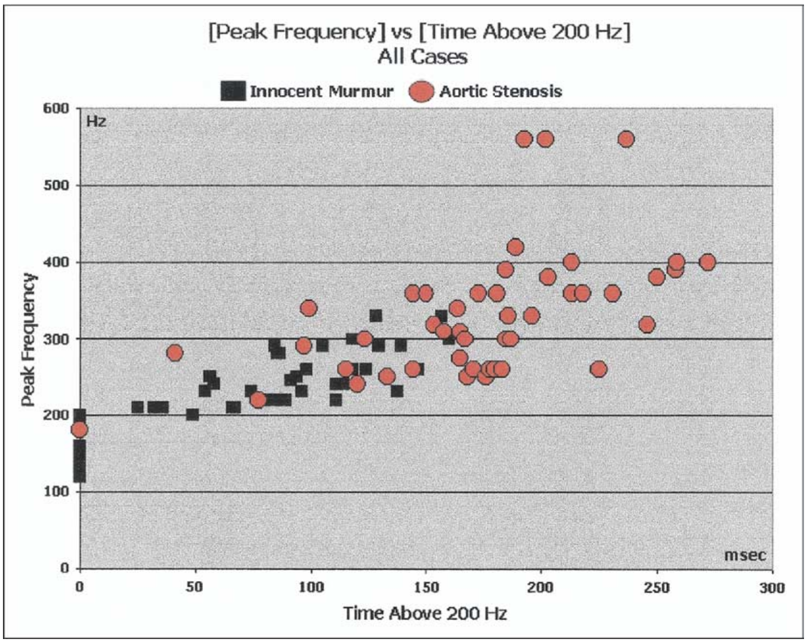

FIGURE 2. Peak frequencies against durations >200 Hz (milliseconds) in all cases. The innocent murmurs (*black squares*) are confined in an area bounded by an upper frequency of 330 Hz and duration (>200 Hz) of 160 ms.

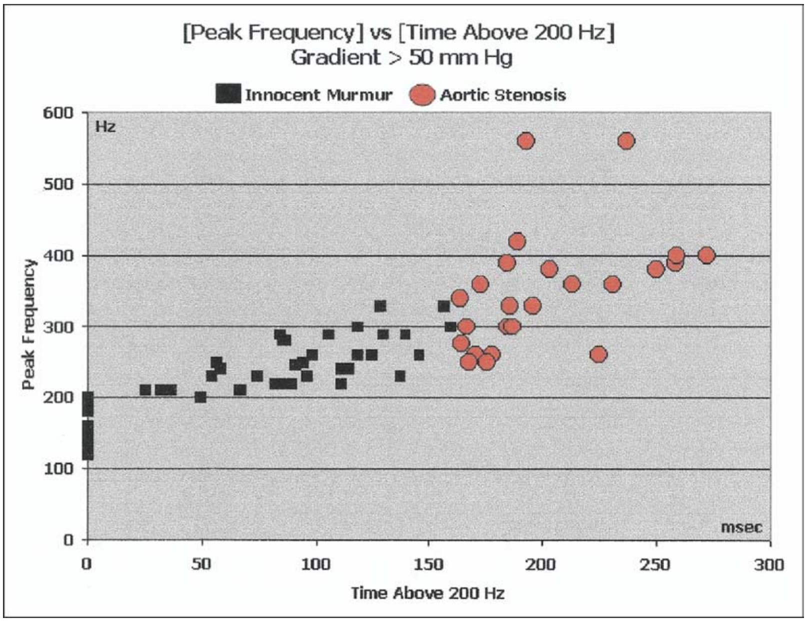

FIGURE 3. Peak frequencies against durations >200 Hz (milliseconds) for all subjects with innocent murmurs against those with more significant degrees of aortic stenosis (systolic pressure gradients >50 mm Hg). In this example, the groups are clearly separated. The subjects with aortic stenosis *(red circles)* fall outside the limits occupied by the innocent murmurs.

proach might be of optimum benefit in distinguishing the innocent murmur from that of aortic stenosis. First, one ascertains the peak frequencies. When they decrease to <200 Hz, one may rule out aortic stenosis of any significant degree. When they are >330 Hz, normality can be excluded.

Next, when peaks are between 200 and 330 Hz, one determines the durations >200 Hz. When these are <160 ms, all but relatively minor grades of stenosis may be ruled out. When >160 ms, hemodynamically significant stenosis would be more likely, generally prompting the need for more detailed clinical analysis.

This method is inexpensive, simple, and requires little time or expertise for rapid analysis of murmurs at the recording site. Moreover, the sounds can also be transmitted by telephone to distant sites for further analysis or storage. Waveform display with optional filtration also allows for standard phonocardiographic analysis. We believe that this latter feature could help to rehabilitate phonocardiography, a well-established method that is useful not only for clinical analysis but also critical for the proper teaching of cardiac auscultation.[9]

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