# Cardiac Auscultation

## A Glorious Past—And It Does Have a Future!

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***Abstract*****—**Cardiac auscultation remains an important part of clinical medicine. The standard acoustic stethoscope, which has been useful for more than a century, cannot process, store, and play back sounds or provide visual display, and teaching is hindered because there is no means to distribute the same sounds simultaneously to more than one listener. Modern portable and inexpensive tools are now available to provide, through digital electronic means, better sound quality with visual display and the ability to replay sounds of interest at either full or half speed with no loss of frequency representation or sound quality. Visual display is possible in both standard waveform and spectral formats. The latter format is readily available and provides certain advantages over the time-honored waveform (phonocardiographic) method. Both methods, however, can and should be used simultaneously. Sound signals obtained electronically may then be subjected to objective visual and numerical analysis, transmitted to distant sites, and stored in medical records. Signal analysis shows early promise for clinical application, such as in the assessment of severity of aortic stenosis and in the separation of innocent from organic murmurs. In addition to their clinical value, these methods provide a critical vehicle for the teaching of cardiac auscultation, a method that can and should be preserved for future generations. **(*Circulation*. 2006;113:1255-1259.)**

**Key Words:** cardiac auscultation ■ stethoscopes ■ heart sounds ■ heart murmur ■ spectral analysis

In a previous essay,[1] I stated that cardiac auscultation remains an integral and important part of clinical medicine. The monitoring of sound waves from the surface of the body with a stethoscope continues to provide an important source of clinical information. Together with the overall bedside examination, the use of the stethoscope is not only cost-effective but also cannot be totally replaced by alternative technological methods.

Unfortunately, this mechanical tool cannot store and play back sounds, cannot offer a visual display, and certainly cannot process the acoustic signal. But perhaps the most important shortcoming is its inability to transmit sounds simultaneously to multiple listeners. This lack of a common "audio platform" is the most serious obstacle to effective teaching of cardiac auscultation, a deficiency that has reached serious proportions throughout our educational institutions.[2]

Electronic stethoscopes have been available for many years, but these devices per se have generally provided little or no improvement over their mechanical predecessors. In addition, they have been expensive, and they often introduce objectionable background noise. Even more limiting, however, is the fact that these devices have lacked the means to interface with computers that can play back the sound at variable speeds without distortion in pitch, display a phonocardiograph for visual reference, store and later recall the sound for effective differential diagnosis, and conveniently transmit the sounds to remote sites. With the advent of miniaturized and powerful technologies for computing, however, these limitations are rapidly receding.

### Electronic (Digital) Stethoscopes

At present, there are at least 5 such devices available (Cardionics Corp, Webster, Tex; Point of Care, Corp, Toronto, Canada; 3M Corp [Littman], Minneapolis, Minn; Welch Allyn Corp [Meditron], Skaneateles, NY; and American Diagnostics Corp, Hauppauge, NY), and all appear to possess satisfactory sound quality and amplification while at the same time minimizing background interference. Costs have also been falling, and these electronic stethoscopes are now priced only slightly above most good-quality mechanical stethoscopes. One model (Point of Care, Inc, Toronto, Canada) can be inserted into a standard acoustic stethoscope, thus converting it inexpensively into a digital device. The next key requirement for these digital devices is a seamless interface between the device itself and a computer host; most commercially available units, indeed, do provide some means of communication to either a personal computer or a handheld device (or both) operating under PalmOS or Windows operating systems.

There are several features that I believe should be incorporated into these digital devices to achieve the

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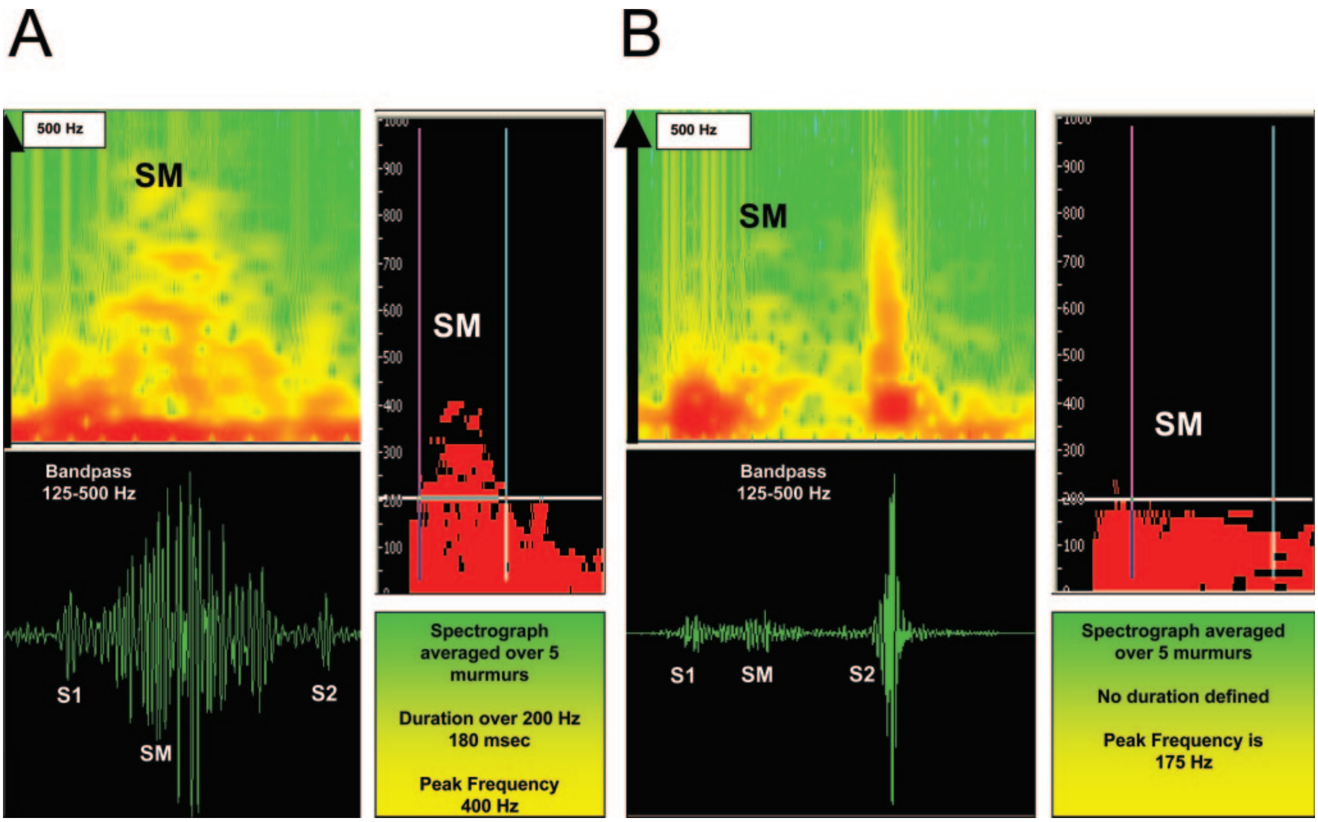


**Figure 1.** A, Example of a spectral display (upper left panel) recorded simultaneously with a waveform display (below) in a patient with severe aortic stenosis. The waveform image was obtained with a band-pass filter (125 to 500 Hz). A systolic murmur is noted that has a crescendo-decrescendo contour in the waveform display, whereas it also shows a crescendo-decrescendo frequency pattern in the spectral image. This latter image presents a colored plot in which the relative signal intensities correlate with the colors, ie, greater intensity is shown in orange and lesser intensity in yellow. Absence of sound is shown in green. The panel at the right shows a spectral average of murmurs derived from multiple cycles in this case. It is color coded to demonstrate only more intense frequencies uniformly in red, ie, after a given "cutoff" attenuation (−25 dB in this example), the red changes abruptly to black. Displayed in this way, this latter image shows a relatively high-peak frequency of 400 Hz (vertical scale at the left). This display also allows for measurement of the time duration for the murmur to exceed any arbitrary frequency level, in this case 200 Hz. Example B demonstrates a similar display for an individual with an innocent murmur, which appears primarily in early systole and does not reach a peak frequency of 200 Hz. SM indicates systolic murmur.

proper goals. These include good sound quality, visual display, playback capability, database for reference, and the ability to store and transmit to distant sites. These features are discussed below.

## Sound Quality

Sound quality must be at least as good as that provided by mechanical devices. Electronic amplification of all sounds, particularly within the low-frequency domain, may allow the examiner to detect sounds that are otherwise inaudible or, at best, indeterminate. In this regard, I have personally experienced better detection of soft third or fourth heart sounds and murmurs of aortic and mitral regurgitation, all of which were otherwise inaudible through standard acoustic means.

## Visual Display

Standard waveform (phonocardiographic) display should be accomplished with a cursor that sweeps synchronously with playback, either in real time or after completion of the examination. In this way, the examiner can follow visually while listening. Spectral display should also be an option, as discussed below. Simultaneous display of a single-lead ECG should be available soon and should be useful in timing the onset of ventricular systole. This could aid in detecting the presence of fourth heart sounds and distinguishing these from sounds that occur during early systole, ie, first sound components and ejection sounds.

Spectral display of cardiovascular sounds was introduced more than 50 years ago by McKusick and coworkers[3] and formed the basis of a very useful analytical characterization of cardiac murmurs. Because it could not be computed quickly and conveniently at the bedside by the tools of the day, it was abandoned in favor of standard waveform phonocardiography. Now this display can be computed quickly by almost all platforms. This allows for the enhancement and extension of many of the methods developed earlier through waveform display.

Spectral display of sounds demonstrates sound frequencies on the vertical axis, time on the horizontal axis, and intensity through the use of various colors or shades of gray (Figures 1 through 3). This display allows for rapid visual analysis of morphological patterns of sounds and

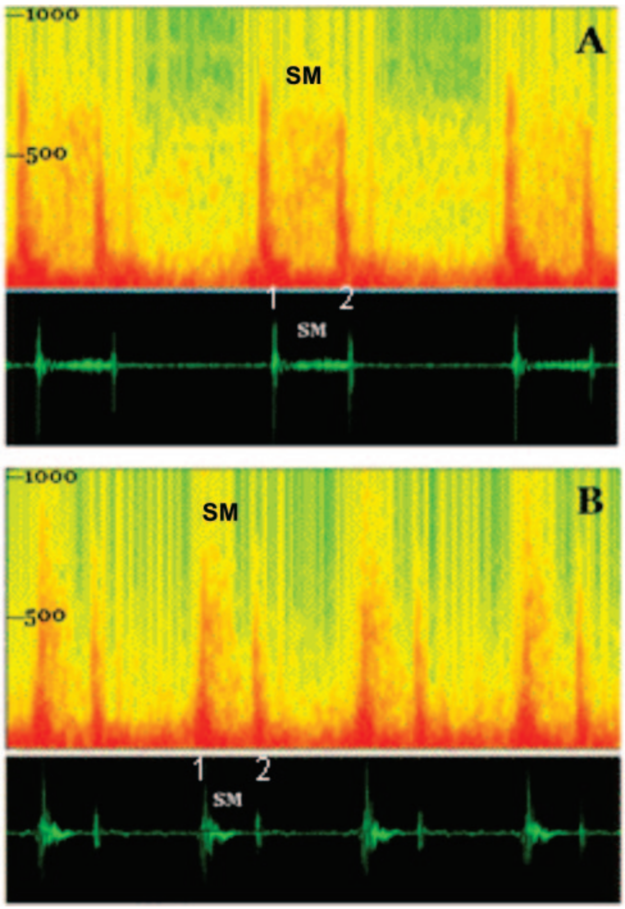


**Figure 2.** A, Mitral regurgitation: spectral (above) and waveform (below) plots. The waveform display exhibits a pansystolic murmur (SM), which gradually intensifies to the second heart sound (2). The spectral display shows a slowly rising peak frequency pattern throughout systole, which reaches a high in the range of 700 Hz; it possesses an even intensity pattern throughout the entire frequency range. B, Ventricular septal defect involving the muscular portion of the septum. A murmur (SM) is confined to the early part of systole. The spectral images above display relatively high peak murmur frequencies, exceeding 600 Hz, which are decrescendo in contour.

murmurs. It can even be rendered in a 3D format, wherein quantitative intensity within a given frequency domain can also be displayed. Spectral display can be rendered and viewed quickly at the bedside before transmission and storage.

The spectrograph possesses several advantages. First, scanning the spectrograph along any particular frequency line corresponds to filtration of the phonocardiograph around that frequency, without the introduction of baseline vibrations and other noise artifacts. Second, plotting the frequency intensities on a logarithm or decibel scale allows a large range of intensities to be plotted meaningfully on the same graph. In this way, a single spectrograph renders the sound as an image, and abnormal patterns can be recognized visually. Third, peak frequencies and signal duration at arbitrary frequency levels can be measured. Although absolute values for peak frequency are difficult to ascertain, one can display, through color manipulation, the highest frequencies demonstrable up to a given “cut-off” attenuation, such as −25 dB (Figure 1). Finally, averaging over multiple cardiac cycles is possible and can enhance the display of periodic phenomena such as murmurs (Figures 1A and 1B). This averaging process tends to suppress noise artifact and increase the accuracy of spectral analysis.

The spectrograph can also complement echocardiographic/Doppler techniques. It can aid in determining which patients to subject to the expense of echocardiography. For instance, using peak frequency and murmur duration, we have recently demonstrated its ability to separate the innocent murmur from that of hemodynamically significant aortic stenosis.[4] Other related methods have been used to distinguish innocent murmurs from those produced by cardiac disease in children.[5] In addition, spectral analysis can enhance and confirm information gained from echocardiography: Applying similar measurements as noted above, one can estimate the severity of valvular aortic stenosis.[6–8] Peak frequencies are also potentially useful for identification of such conditions as mitral regurgitation, ventricular septal defect, and others (Figures 2A and 2B).

Increased peak frequencies within the various heart sounds (transients), such as the aortic and pulmonic components of the second heart sound, are potentially useful in detecting abnormal pressure in the pulmonary circuit[9] (Figure 3). Presence and timing of sound splitting also can be detected relatively easily through this means. Ejection sounds (clicks) may also be recognized more easily, especially when they occur close after the normal first heart sound. These sounds often display elevated peak frequencies that equal or exceed those of the normal first heart sound components. Third and fourth heart sounds can be detected and studied through spectral display; in this regard, one study[10] suggested that peak frequency of fourth sounds correlates with severity of diastolic stiffness (reduced compliance) of the left ventricle. To provide timing of these latter sounds, a simultaneous ECG (single lead) will be integrated into the system when desired.

## Playback at Full and Half Speed

Digital devices should be capable of playback with accurate reproduction of the original sounds. Also, when playback is performed at reduced speeds, it should be accomplished without distortion in pitch. This latter feature is very useful for fast heart rates, more precise identification of sound splitting, and more precise interpretation of murmurs.

## Database of Normal and Abnormal Heart Sounds

A database that is readily accessible at the bedside would help examiners, especially those who are inexperienced, identify sounds or murmurs of a given patient, because they could be compared immediately with those derived from various prerecorded sample sounds.

## Storage and Transmission to Distant Sites

Once obtained digitally, sounds may be stored easily and incorporated into electronic medical records for subsequent

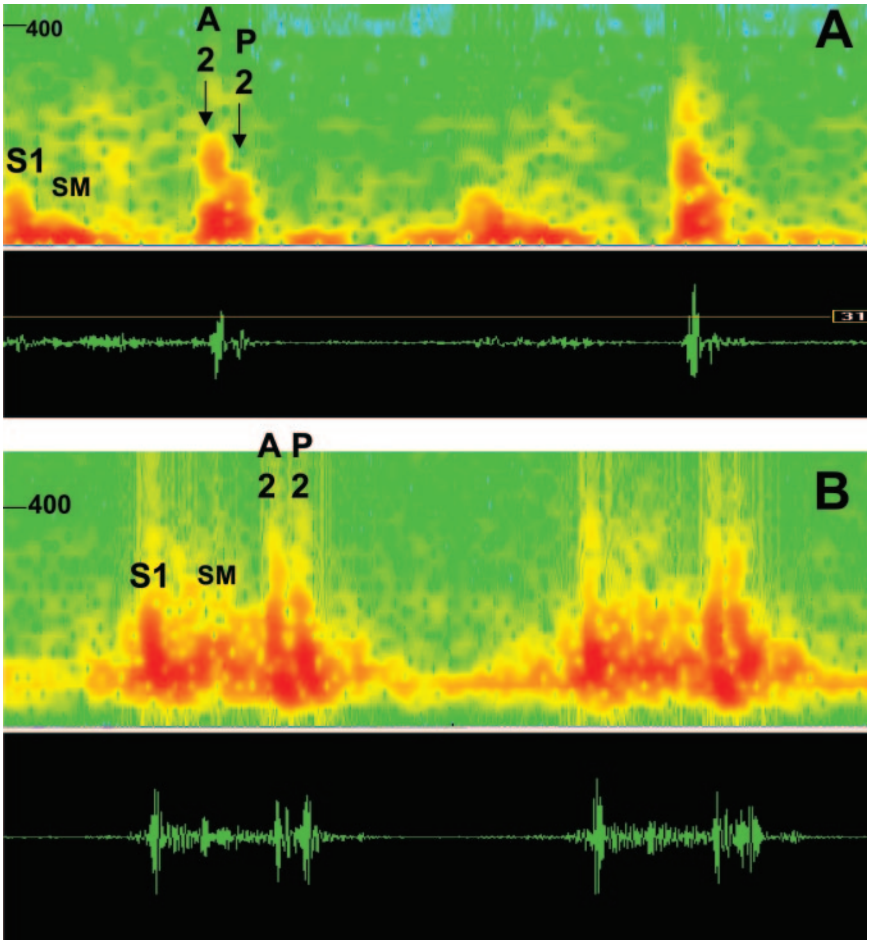


**Figure 3.** Examples of second heart sound characteristics, normal and abnormal. A, Normal second sound, demonstrating both aortic (A2) and pulmonic (P2) components. Peak frequencies of the aortic component exceed those of the pulmonic. B, Spectral display from a patient with an atrial septal defect. In this example, the second sound is widely split, with the peak frequency of the pulmonic component equaling or exceeding that of the aortic component. A systolic ejection murmur (SM) is also displayed in this instance, which contains relatively low peak frequencies in the range of 250 Hz. S1 indicates first heart sound.

review and comparison. Transmission, analysis, and storage are also possible at any distance via e-mail. As an example of the potential utility of such a process, Dahl et al[11] have recently shown that heart murmurs may be recorded in outlying clinics and transmitted to specialized centers for auditory review and analysis by cardiologists. This latter study demonstrated that after such a review, skilled remote auscultation is accurate in properly identifying innocent murmurs and distinguishing them from most murmurs caused by structural diseases, thus avoiding the expense of patient travel and further consultation. If the methods of mechanical analysis of murmurs, as described above, are proved to be reliable, then the requirements for expert intervention would be reduced, and costs would be further mitigated.

## Teaching of Cardiac Auscultation

When sounds are collected through electronic means, the foregoing limitations to teaching are completely removed. Immediate playback simultaneously to multiple listeners is accomplished easily, and this playback can also be performed at reduced speeds without distortion of sound pitch. Simultaneous visual display involving a moving cursor provides to the student precise identification and localization of specific sounds within the cardiac cycle. With portable handheld devices and wireless communication, audiovisual presentations to groups of any size are possible in both bedside and auditorium settings. Prerecorded audiovisual sound presentations are available for use by instructors and students alike and can be employed for home use, as well as in a classroom environment.

## Conclusions

The time has arrived for the medical profession to keep pace with the technological methods now available and to employ them in the practice and teaching of cardiac auscultation. Auscultation at the bedside can now be enhanced by better sound quality and by the ability to replay sounds of interest in either full or half speed with no loss of frequency representation or sound quality. This permits the acquisition of a visual display of sounds in both standard waveform and spectral formats. The latter format is readily available and provides certain advantages over the time-honored waveform (phonocardiographic) method. Both methods, however, can and should be used simultaneously.

Signals obtained electronically may then be subjected to objective visual and numerical analysis, transmission to distant sites, and storage in medical records. Signal analysis shows promise for clinical application, such as in the assessment of severity of aortic stenosis and in the separation of innocent from organic murmurs. Perhaps most importantly, however, these methods provide a critical vehicle for the teaching of cardiac auscultation—a method that can and should be preserved for future generations.

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## Disclosures

The author serves as a consultant to Point of Care, Inc, Toronto, Canada, producer of equipment for recording, processing, and displaying clinical data derived noninvasively from human subjects.

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