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Editorial

The Exciting Future of Digital Phonocardiology

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Detecting structural abnormalities of the heart such as aortic insufficiency or the presence of a ventricular septal defect (VSD) remains an important clinical problem. Many such abnormalities can be detected by careful auscultation but generally only seasoned cardiologists are able to reliably detect important but subtle auscultatory findings. Although echocardiography is superb in identifying and characterizing such abnormalities, this technique is expensive and neither suitable for mass-screening or for continuous monitoring. In addition, its operation requires considerable knowledge and skill. Similar problems exist with cardiac catheterization methods. In this brief editorial we suggest that digital phonocardiography has an exciting future, especially in situations where echocardiography and cardiac catheterization are impractical.

As an example, we have shown that electrocardiographically (ECG) -synchronized digital subtraction and spectrographic analysis can be used to study heart sounds and murmurs in an entirely new way. While older phonocardiograph designs remain useful to study cardiac disorders, this new approach offers two new dimensions: (1) the ability to separate the deterministic component of heart sounds from murmurs by digital subtraction, and (2) the ability to apply spectrographic analysis to the isolated components. The method begins by constructing a series of "murmurgrams", defined as the resulting signal when one subtracts phonocardiogram cycle j+1 from cycle j. A murmurgram is thus simply the difference between the acoustic emissions of two successive heart beats. The QRS complex of the electrocardiogram (ECG) is used as a marker of the beginning of each cycle so that any two successive phonocardiograms can be aligned and subtracted to produce a murmurgram. We found that a normal murmurgram does not vary significantly in either time-domain, or frequency-domain properties across the cardiac cycle; that is, a normal murmurgram is more or less flat across the cardiac cycle (within the limits of system noise effects and biological variability). By contrast, increases in the murmurgram signal can be found in regions of the cardiac cycle associated with intracardiac turbulent blood flow resulting from cardiac structural pathology, as in cases of aortic stenosis or in patients with a ventricular septal defect.

We have also studied another technique, which we call Color Spectrographic Phonocardiography (CSP), as a noninvasive means to detect and characterise heart murmurs. Figure 1 shows sample phonocardiographic (middle) and electrocardiographic (top) recording obtained from a healthy six year old girl with an innocent murmur. The corresponding color spectrogram is shown in the bottom. The recording is of 5 cardiac cycles over 3.35 seconds. Note that the frequency of the murmur is mostly under 200 Hz. Notice how the two main heart sounds (S_1 and S_2) can be readily identified in the signal [1]. Figure 2 presents data for an 8 month old girl with a VSD. Five cardiac cycles are shown. The color spectrogram (figure bottom) indicates that the murmur has frequency components extending to 700 Hz [1]. We have also investigated mathematical simulation of the phonocardiogram (PCG). Figure 3 shows a PCG from a simulated atrial septal defect (ASD) case. The murmurgram and corresponding color spectrogram are shown in the bottom panels. The simulated PCG is of 1 cardiac cycle covering an elapsed time of 0.7 seconds. Note that the murmurgram isn't "flat" between $S_1$and S_2. The mid systolic murmur in the murmurgram in this case has frequency components that extend to around 600 Hz [2]. Finally, in other research, we developed a novel, low complexity method for the detection of the first and second of heart sounds (S_1 and S_2, respectively) and the periods of systole and diastole without using an electrocardiogram reference. The algorithm uses a technique called *empirical mode decomposition* to produce time domain intensity envelopes of the heart sounds [3]. Figure 4 presents a recording for a 6-year-old girl with a VSD. The corresponding ECG and the PCG are shown [3]. While much work still remains to be done to develop a comprehensive computerized program for routine phonocardiographic analysis, our eventual hope is that continuing work in digital phonocardiography will lead to the development of inexpensive non-invasive clinical instrumentation that will be valuable both for initial cardiac diagnosis as well as for perioperative cardiac monitoring [4].

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