

## **A New Tool in the Detection of Innocent Heart Sounds and Murmurs in Children**

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### **Abstract**

A paradox in present health care delivery is the documented deficiency of cardiac auscultation skills among primary care physicians and the wide prevalence of innocent heart murmurs in children. The net result is an excess of stressful, expensive consultations with cardiologists. Blending Heart Energy Signatures with phonocardiographic intensity frequency spectra, a method of analyzing previously recorded heart sounds has been developed. With the objective of describing murmurs and sounds as being normal or abnormal, 65 patient acoustic heart recordings were studied. Six murmurs were

analyzed per recording to a total of 433 murmurs. 205 cases of Still's murmur were shown to have a distinct pattern of narrow frequency range (90-110 Hz) with a midpoint "obelisk" appearance. Innocent systolic flow murmurs also had a distinctive pattern which, combined with murmur intensity and normal splitting of S2, allow differentiation from atrial septal defect . Organic murmurs i.e. obstruction, regurgitation, are also studied, allowing still greater confidence in analysis. Mid-systolic clicks and systolic ejection clicks are easily identified. An additional but important finding has been precise, objective measurement of the intensity of murmurs. Widespread adaptation of this procedure could increase the efficiency and cost-effectiveness of pediatric health care.

Word count: 195 words

**Key Words:** Innocent Heart Murmur, Still's Murmur, Phonocardiography, Heat Energy Signature, Cardiac Auscultation

**Acknowledgements:** The authors thank Richard B. Goldbloom OC.MD, FRCP(C), retired Professor and Head Department of Pediatrics , Dalhousie Medical School, Halifax, N.S. and Thomas M. Biancaniello, MD, FACC and Chief Pediatric Cardiology University of New York at Stony Brooks for their aid in the preparation of the manuscript. Authors thank Olga Saynina, MA (Stanford University School of Medicine) for help with statistical analysis using SAS.

## **INTRODUCTION**

Of 970 new patients seen at pediatric out patient clinics of a teaching hospital in 2003, 64.2 percent were diagnosed as innocent murmur (1). While innocent systolic murmurs are easily

recognized by cardiologists on auscultation, such clinical skills are rarely acquired by primary care physicians during medical school training (2,3,4,5,6), nor by certain specialties (7). A less expensive, readily attainable and highly accurate method to distinguish innocent heart sounds and murmurs would significantly benefit health care delivery.

While the phonocardiographic procedure (PCG) has been available for many years, its limitations have precluded significant clinical use. Recent technological developments have allowed high fidelity recording, digitization and digital processing and display of heart sounds, increasing the potential of its clinical acceptance. Using recording electronic stethoscopes (8,9), adhered piezoelectric pad sensors (10), new software (11,12) and ultra-compact solid state digital recorders (13), external USB-based digital sound cards (14), a new functional modality is now available.

Ninova et al. in 1978 (15) performed automated mass screening of children for heart disease using analog PCG timing and intensity signals, with high sensitivity and specificity. New digital technology has improved the effectiveness and portability of such procedures. Donnerstein and Thomsen (10b) analyzed frequency properties of innocent Still's murmur. More recent publications (16,17,18,19,20,21) all reflect the growing interest and progress in this field.

The rebirth of interest in "digital" PCG has been generated by a new form of visual display (16), automated detection of pathological heart murmurs using spectral analysis of continuous wavelet transforms (18) and using a new sound spectral averaging technique to distinguish the innocent murmur from that of aortic stenosis (17). The use of heart energy signature (HES) spectrograms has been developed recently (12, 22), and this study, using PCG, HES and signal processing algorithms, is directed specifically to determine whether heart sounds and murmurs

are innocent, requiring no further investigation. The method proposed describes murmur intensity precisely, as well as the timing, frequency, and normality/abnormality of heart sounds.

For purposes of this study a library of heart sound recordings, primarily of children, was used (24,25). In conjunction with newly developed PCG/HES methodology of analyzing heart sounds and murmurs, these data were used to quantify their properties precisely and to determine their normality by virtue of these newly defined properties. An additional discovery is a precise, objective method for accurately grading the intensity of a heart murmur. This represents a valuable additional tool for determining the clinical significance of a heart murmur. PCG/HES is an inexpensive and accurate method of determining the clinical status of heart sounds and murmurs. Subject to confirmation through clinical trials, it has the potential to increase the efficiency and cost-effectiveness of this element of health care delivery.

## **MATERIALS AND METHODS**

The objective of this study was, simply, to assess the auscultatory recording as being normal or abnormal, with the designation of ‘abnormal’ implying that additional investigation is required. For the purposes of this study it was assumed that, with the exception of the third heart sound (S3), any other diastolic auscultatory findings were abnormal. Other rare events, e.g. pericardial friction rub and early diastolic rustle were not included in the normal/abnormal analysis of heart sounds in this study.

Innocent systolic murmurs were analyzed in detail. These included the vibratory Still’s murmur (23) and the “flow” murmur, related to increased ventricular stroke volume. The

murmur of atrial septal defect (ASD), also a flow murmur, was recognized by its coarseness, its intensity and by the abnormal splitting of S2.

To determine their clinical status, all systolic murmurs were classified in one of the following categories:

Vibratory murmur

Flow murmur

Obstructive murmur with post-stenotic dilatation (aortic valve stenosis)

Obstructive murmur due to tubular narrowing without post-stenotic dilatation  
(infundibular pulmonary stenosis)

Murmur of regurgitation (mitral regurgitation and ventricular septal defect)

Thus, the positive features of both innocent and organic murmurs were documented. To further improve the detection of organic sounds, the systolic ejection click and mitral valve prolapse sounds were also studied.

All recordings were prospectively collected by one of the authors (DLR) in the clinical settings of IWK Medical Center (Dalhousie University, Nova Scotia, Canada) over the course of 10 years (25). In all cases considered matching clinical and auscultation diagnosis was also available.

Later they were systematized into a heart sound database (24) containing over 300 clinical recordings and was utilized in cardiac auscultation teaching in Canada and elsewhere (6,33,34).

*All available files from the database were utilized for this study, Ethics approval is not required.*

The majority of heart sounds were recorded at the bedside using an “AVR” (audio visual recorder, manufactured by Cambridge). Heart sounds were recorded with microphones and

converted to digital signals using analog-to-digital conversion (26,27).

**Technical Details:** In this study we utilized the Heart Energy Signature (HES) Method and Format that was recently developed by the present authors (12) to characterize recorded digital heart sound signals stored in the digital wave file format (11 KHz sample rate). The HES method is implemented in a software package Bsignal V3.6 (22) and transformed into a heart sound time-frequency image and presented as a two-dimensional flooded color plot, showing time as the horizontal axis and frequency as the vertical axis. Heart sound energy is represented by varying degrees of black. Different heart sound components are clearly visible as dark blobs. There is a straight forward analogy between HES and musical tones (notes).

To obtain the desired area, i.e. heart sound or portion of murmur for which a HES image is to be shown, that portion of the cardiac cycle is marked. It is then processed using joint signal processing methodology. Further technical details, method validation and its advantages over heart sound spectrograms are discussed in (12). Using this method we could distinguish visually and digitally corresponding frequency (pitch) changes in all heart sounds and murmurs, as well as their timing, duration and intensity. Several averaged and instantaneous characteristics could be extracted from the main HES image for additional insights. In this study, the signal power vs. time obtained from the HES image and the signal amplitude frequency spectrum obtained via Fast Fourier Transform (FFT) were utilized. The FFT method has been used extensively in this analysis, applying it only to a murmur time portion of the signal. This novel approach reveals the time-averaged frequency content of any murmur. All the above characteristics are part of the heart energy signature format (22).

The following analysis template was used in the analysis for all PCG/HES, (hereafter called Audio to Visual A toV ):

1. A PCG recording of 10 to 20 seconds to recognize (a) rhythm (b)systole/diastole and (c) heart sound intensity, using signal energy power vs. time distribution.
2. Establishment of splitting of S2 pattern.
3. Identification of systole measuring the time duration between S1 and S2 and between S2 and S1 on the PCG/HES Power plots, with the longest time duration being diastole.
4. Identification of systolic energy blob by HES and waveform by PCG. When the murmur is shown, HES is recorded for a short portion of the murmur rendering time-frequency properties clearer.
5. Designation of murmur intensity score. This method, currently under study (26), averages ratio of maximal peak-to-peak murmur signal strength to maximal (S1 or S2) signal strength, which will be correlated with clinical data and then graded in the universally used Freeman-Levine method (29,30).

Freeman-Levine Murmur Grade	1	2	3	4	5	6
Score, %	18	45	85	140	350	650

6. The pitch(frequency) of the murmur is analyzed by the frequency spectrum plot of a selected section of the murmur. Medium frequency and bandwidth of murmur are determined at half of its amplitude on the frequency spectrum.
7. The murmur or sound timing identification, i.e. the beginning, end and possible peak of a

murmur, are defined by either PCG or HES power plot. HES power plot can be averaged (across all frequencies, such as shown on Fig. 4) or presented instantaneously (for a given frequency of interest). Abnormal sounds, i.e. ejection click, mid-systolic click(s) are defined in a similar manner.

8. Murmur shape is best demonstrated by the PCG of the consecutively recording of three heart beats. HES power time plot and PCG plot offer a quantitative measurement of murmur's shape.

## **RESULTS**

*Each patient recording has an average duration of fifteen seconds. An average of six murmurs are analyzed from each recording. The murmur classification, number of recordings and number of murmurs studied are as follows:*

Still's murmur 205 (34 patients), innocent flow murmur 42 (7 patients), ASD 42 (7 patients), pulmonary valve stenosis (PS) 42 (7 patients), aortic valve stenosis (AS) 42 (7 patients), mitral valve prolapse (MVP) 24 (4 patients), systolic ejection click 24 (4 patients), regurgitant murmurs i.e. mitral regurgitation (MR), ventricular septal defect (VSD) 24 (4 patients), Tetralogy of Fallot 12 (2 patients). Each sound file contains between 15 to 30 beats.

HES is particularly useful in demonstrating frequency range, as shown in Fig.1. Time averaged frequency spectrum between the start and end point of the murmur, with vertical axis showing the strength (amplitude) of the murmur and horizontal axis shows the frequency.

All cases of Still's murmur (Fig. 2A, 2B,2C) show a distinctive pattern on the frequency spectrum. The murmur, being ejection in timing, is diamond shaped and spectrum plots

consistently show a very narrow frequency band between 90 and 120 Hertz (Hz), peaking at 100-110 Hz

At mid- point, an "obelisk" - like spike is seen. The average median frequency of 205 murmurs is 110.5Hz (sd +- 18 Hz). The musical (vibratory) quality of Still's murmur is accounted for by the narrow frequency band, with average half-width of 19.6 Hz (sd\* +- 13Hz). Those with strong musical quality have half-bandwidth below 11 Hz. Average murmur intensity score is 23% varying between 11% to 49% (sd +- 16.2%).

Recordings of innocent systolic flow murmurs show a common pattern, but with greater variation than the Still's murmur (Fig. 3). Being also ejection in timing, multiple intensity peaks of between 80-131 Hz are seen, but with a wider spectrum of frequencies (75 to 150 Hz) with the medium average frequency being 108.5 Hz (sd +- 14 Hz).

As with the Still's murmur, murmur intensity is low (average is 17.7% varying between 7 to 46% with standard deviation 8.7%) and the average half-bandwidth being 31.2 Hz (sd +- 15 Hz).

The frequency of the systolic flow murmur being significantly larger and lower than Still's is a significant feature.

A distinguishing feature of the systolic flow murmur of ASD is its intensity. Average intensity is 49.5% (sd +- 16 %) , compared with an average of 17.7% for the innocent flow or 23% for Still's murmur. The ASD systolic murmur (Fig. 3B) can be differentiated from Still's murmur by comparing their time averaged frequency spectra and can be differentiated from all other systolic murmurs by the "fixed" split of S2 (Fig.4). Human auditory (auscultatory) appreciation of S2 splitting is less accurate than digital analysis by PCG and minor movement of

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\* Standard Deviation - sd

S2 in ASD can often be demonstrated by this method (Fig. 4). The ASD systolic murmur has a wider frequency spectrum than the innocent flow murmur with the frequency band spanning from lower (65 Hz) to higher (175 Hz) frequencies (Fig. 3B) . Thus, it will be perceived as rougher on auscultation due to the wider and stronger lower frequency portion of the spectrum.

Murmur frequency spectra can vary within a particular recording of an individual patient. Thus, it can be difficult to differentiate ASD flow and innocent flow murmurs by comparing their frequency spectrums only. Low intensity ASD murmurs can only be differentiated using S2 split.

Clinically the murmurs of valvular PS and AS are very similar in timing, intensity and quality. They may only be differentiated by their point of maximal intensity on the chest, changes in S1 and S2, and by the presence or absence of systolic ejection clicks. Peaking in mid-systole, the murmur intensity is above 70%, with a wide frequency band between 50 to 250Hz, making differentiation from the innocent systolic murmurs easy.

Systolic regurgitant murmurs (MR and VSD) are readily differentiated from innocent murmurs by their wider and higher frequency spectrum bandwidth. Timing of the murmur, either pansystolic, early-mid, or mid-late, are other distinguishing features, and the crescendo-decrescendo shape of the ejection murmur is not seen.

The murmurs of infundibular pulmonary stenosis and mid-ventricular obstruction are differentiated from the innocent murmur by their high frequency spectrum and their murmur intensity score.

As with clinical difficulty, the systolic ejection click which follows tricuspid closure so closely, presents some difficulty to AtoV, but can be differentiated by the higher pitch and

greater intensity of the click as compared with tricuspid closure.

Spitting and movement of the components of S2 often present difficulty to the auscultator. Use of the HES derivative, power plot, allows for precise millisecond measurement of the degree of spitting and movement of the S2 components (Fig 4).

The mid systolic click or clicks of MVP are readily demonstrated by AtoV and present no difficulty in diagnosis (Fig. 5).

SAS V8 statistical analysis package was utilized in this study. For this purpose innocent murmurs were marked as zeroes and abnormal murmurs were marked as "1". Using the Student t-test and ANOVA statistical analysis, the difference in maximum frequency between the Still's murmurs and pathological murmurs was NOT statistically significant (p-value of 0.138). However, the difference in the band-width (depicted in obelisk-like spectra) between the Still's murmurs and pathological murmurs was statistically significant to a p-value of <0.0001 (see also (35) to illustrate difference between Still's murmur and obstructive murmur of pulmonary stenosis).

## **DISCUSSION**

The frequency of innocent murmurs in children and the lack of cardiac auscultation (CA) skill by primary care physicians have been alluded to. Referral to skilled auscultators (cardiologists) is both expensive and stressful to the patient and parents. *If cardiac ultrasound is employed in the diagnosis the cost per patient, while varying from clinic to clinic, could be as much as US\$1,000.* While few reports of intervention in teaching methods and assessment of

student's CA skill are available, evidence indicates that the teaching of CA has not been effective (5,6). A difficult skill to acquire, CA depends upon inborn talents of pitch and timing perception of the student and an extended exposure time.. It is probable that teaching methods may never succeed in teaching many primary care physicians the ability to determine with conviction whether certain heart sounds are normal or abnormal. Even skilled auscultators may at times differ in their interpretation of an auscultatory event. The incidence of amusia (inability to perceive changes in pitch) being five percent in the population (32), is another factor in the prevalence of low CA skill of family physicians.

This study, based on objective findings, denotes the possibility of determining whether heart sounds and murmurs are normal or abnormal. The AtoV method exchanges auditory perception for a visual one, eliminating individual perceptions of pitch and timing from the assessment of heart sounds and murmurs. AtoV also adds a new set of tools for clinical auscultation and research into heart sounds properties.

We have shown Still's and innocent systolic flow murmurs can be identified using their own distinctive properties with this identification being performed using interactive PC computer based software. Further, abnormal murmurs and sounds can by themselves be identified, rendering AtoV to be a potentially very useful clinical tool. HES is a significant addition to the procedure, particularly in respect to analysis of murmur's frequency, timing and power.

The current method of grading intensity of murmurs (29,31) is subjective. In many instances it lacks sufficient intensity resolution to differentiate normal from abnormal. Murmur intensity is an important factor in analyzing normality/pathogenicity of murmurs. The new murmur score method described here should be a clinical asset not only for such differentiation,

but also in the tracking of organic murmurs.

The difficulty of eliciting the pitch and timing of the systolic ejection click, an abnormal and at times the sole abnormal finding, is well known and can be shown accurately by AtoV. The systolic flow murmur of ASD, usually in the grade 2-3/6 range (45-85% on new murmur intensity score) is easily differentiated from the innocent flow murmur, not only by the degree of splitting of S2, but by the quantitative ratio of murmur intensity and murmur spectrum frequency bandwidth. The ability to identify organic systolic murmurs, including valvar regurgitation and obstruction, and tubular obstruction as in infundibular pulmonary stenosis, is an asset in defining the murmur as organic requiring further study.

The recording of heart sounds for analysis by AtoV is simple and inexpensive. The cost of recording equipment being approximately \$350-400. The ease of the recording procedure allows application at the point of care during cardiac auscultation. Recorded heart sounds can be stored in Mp3 or wave file format as a part of the electronic patient record, this way changes due to aging can also be analyzed.

The interpretation of the AtoV procedure currently requires a skilled person such as a cardiologist. Should further clinical experience indicate that AtoV be made available as a clinical procedure, automation of the interpretation must be made available. An interim method of interpretation would be to email heart sound recordings to a cardiologist in an academic center. Current implementation of the method is computer-interactive, and is available in a commercial software package (12). Further clinical studies are required and are planned.

## **COMPETING INTERESTS**

DLR declared that he has no competing interests. VVK and VVP have stock ownership in Biosignetics Corporation, Exeter, NH, they are also authors of patent application for Heart Energy Signature Method, U.S. Patent Application for Patent Ser. No. 11/064240.

## **AUTHORS CONTRIBUTIONS**

DLR conceived of the study and its design, coordinated the study, participated in the heart sound data analysis and drafted the manuscript. VVK conceived of the study, and participated in its design and coordination, conducted heart sound data analysis and helped to draft the manuscript. VVP developed analysis methods, participated in the heart sound analysis and helped to draft the manuscript. All authors read and approved the final manuscript.

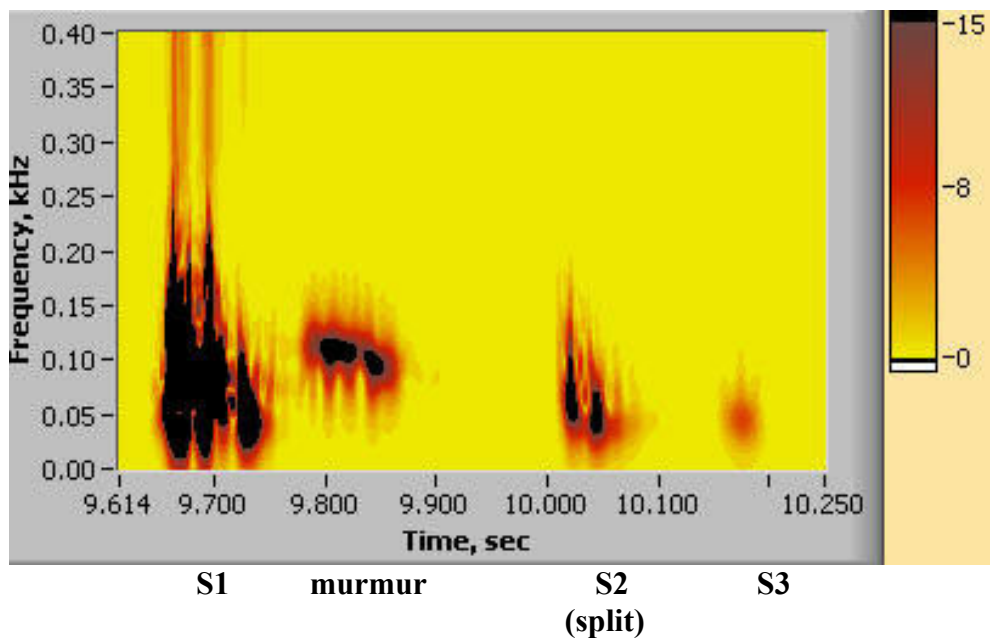
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[http://www.bsignetics.com/papers/PAS%20POSTER%20StillsMurmur\(final\).pdf](http://www.bsignetics.com/papers/PAS%20POSTER%20StillsMurmur(final).pdf)



**Fig. 1 Heart Energy Signature (HES) of one cardiac cycle showing ejection timing and well defined frequency range of Still's murmur**

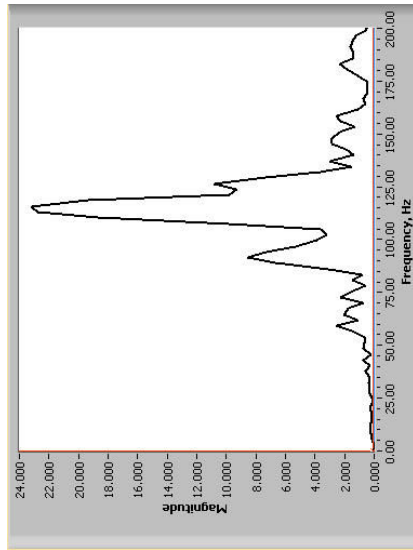


Fig. 2A Case 1

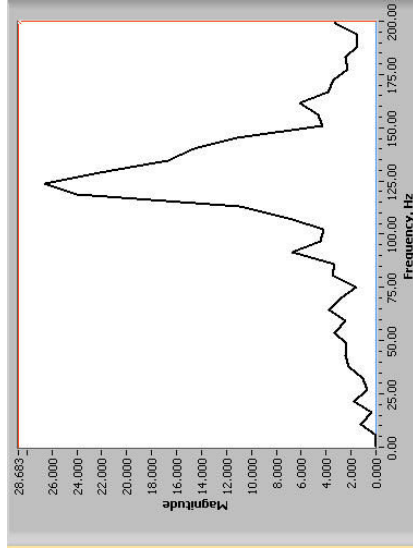


Fig. 2B Case 2

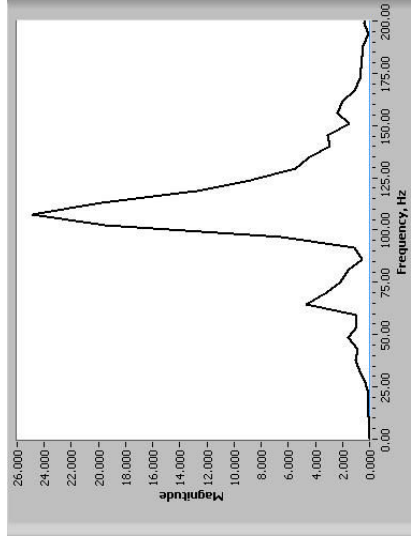
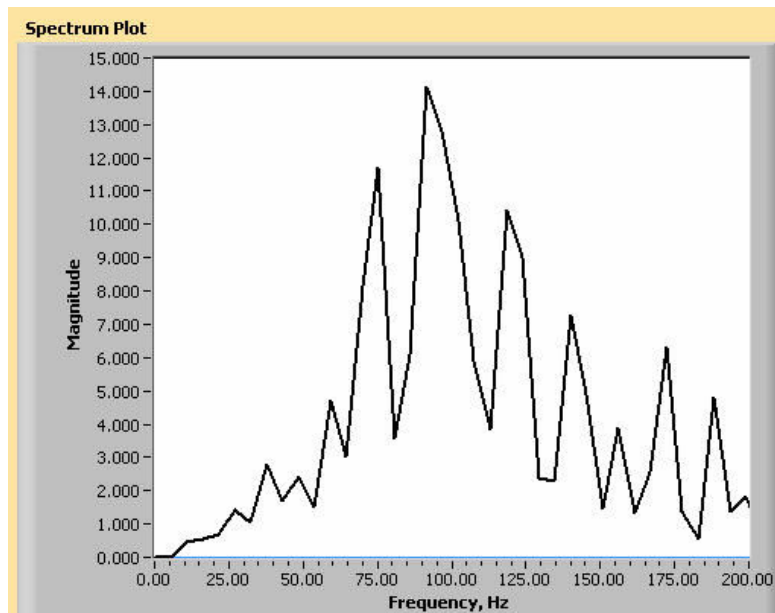
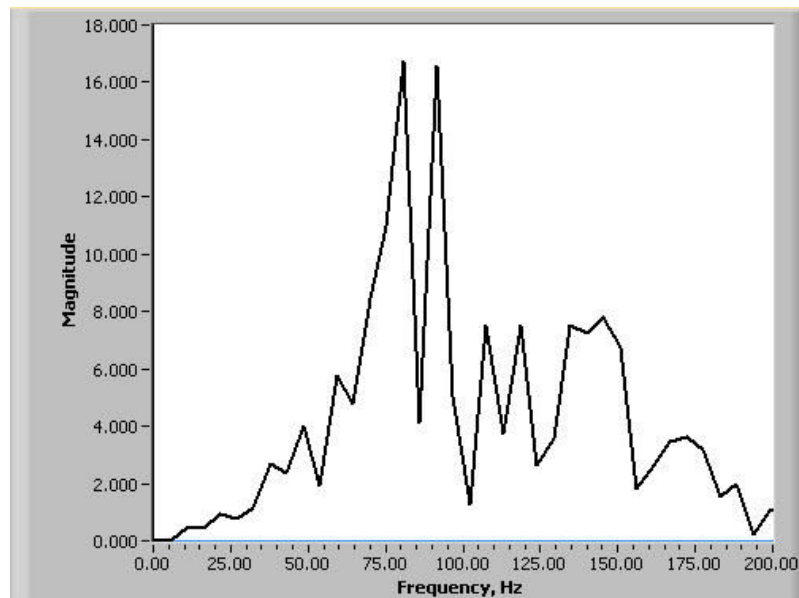


Fig. 2C Case 3

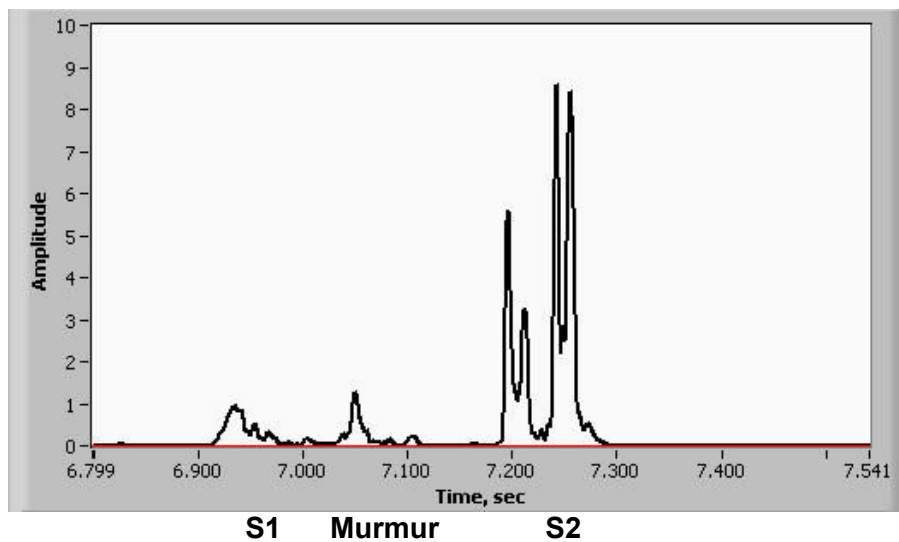
FTT spectra of three cases of Sill's murmur showing similar frequency range and obelisk appearance



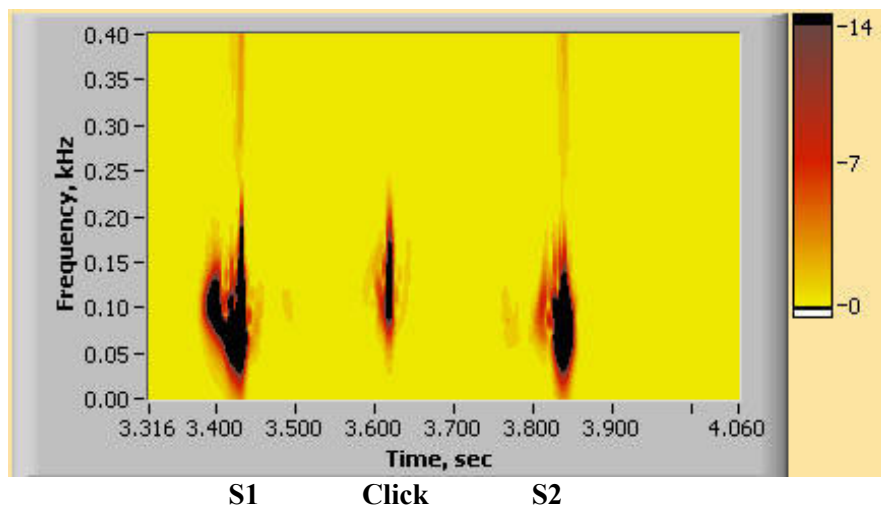
**Fig. 3A** Frequency spectrum of innocent pulmonary systolic flow murmur, showing sawtooth form and frequency range.



**Fig. 3B** Frequency spectrum of systolic ejection murmur of ASD showing increased magnitude and irregularity of magnitude and frequency



**Fig. 4 – HES derivative showing Power Amplitude vs Time plot of ASD. The ease with which degree of splitting of S2 components can be accurately measured can be seen. In this case the degree of S2 spitting is unchanged with respiratory phase.**



**Fig. 5 HES recording of single mid systolic click of floppy mitral valve**