

1: [Curr Heart Fail Rep](#). 2007 Sep;4(3):164-8.

## The third heart sound for diagnosis of acute heart failure.

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Dyspnea is a common presenting complaint in the emergency department (ED). Rapid identification of heart failure as the etiology leads to early implementation of targeted therapies. Although having only intermediate sensitivity, the S3 is a highly specific finding among older adults with heart failure. Identification of an S3 by routine auscultation can be problematic given the chaotic and noisy ED environment, patient comorbid conditions, and intolerance of ideal positioning for auscultation. Technologies using computerized analysis of digitally recorded heart tones have recently been developed to aid the clinician with bedside detection of abnormal heart sounds. Data using these technologies and their applications in the ED are reviewed as well as implications

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## **\_S3 GALLOP**

### **Introduction**

Dyspnea is a common complaint that leads to as many as 2.5 million clinician visits per year in the U.S.<sup>1</sup> Numerous disorders can cause this sensation of uneasy breathing or respiratory distress including heart failure, asthma, COPD, metabolic acidosis, airway obstruction, neuromuscular disorders, and anxiety/panic disorder. Rapid identification of those with heart failure leads to the early implementation of appropriate, evidence-based, and symptomatic therapies.

Heart failure is a global public health issue of epidemic proportions<sup>2</sup> and represents a tremendous burden to overall healthcare costs. At least 5 million Americans have heart failure and approximately 550,000 new cases are diagnosed each year in the US alone.<sup>3</sup> The incidence is expected to continue to increase dramatically due to our aging population, improved survival from acute coronary syndromes, and advances in cardiovascular disease management.<sup>4-6</sup> Consequently, as many as 10 million people in the U.S. are expected to have heart failure by the end of this year.<sup>7</sup> With an estimated annual cost of \$33.2 billion dollars, heart failure is among the costliest cardiovascular illnesses in the United States.<sup>3</sup> Hospitalization for heart failure exacerbation accounts for the largest care expenditure. In fact Medicare data demonstrate an estimated cost of \$5912 per discharge, more than double any cancer diagnosis.<sup>3, 8, 9</sup>

Heart failure is a complex clinical syndrome characterized by impaired myocardial performance including systolic or diastolic dysfunction, neuroendocrine system activation, and intravascular volume overload. It can be simplistically defined as a *clinical syndrome* resulting from any structural or functional cardiac disorder that impairs the ability of the ventricle to *fill with or eject blood*.<sup>10</sup> The cardinal manifestations are dyspnea and fatigue (exercise intolerance)

as well as fluid retention (pulmonary congestion and peripheral edema). A better emergency department or acute care term would be “acute heart failure syndrome” (AHFS), defined as a gradual or rapid change in heart failure signs and symptoms resulting in a need for urgent therapy.<sup>11</sup> These signs and symptoms are primarily due to pulmonary congestion from elevated left ventricular (LV) filling pressures and can occur in patients with preserved or reduced ejection fraction. The term “diastolic dysfunction” refers to an abnormality of LV filling or relaxation; with the addition of effort intolerance and dyspnea it is called “diastolic heart failure” or “acute heart failure with preserved ejection fraction”.<sup>12-14</sup> AHFS admissions are about 50% female, approximately 75% will have known heart failure, and nearly 50% will have preserved EF.<sup>15-17</sup> The majority of heart failure in the western world is due to coronary artery disease, hypertension, and dilated cardiomyopathy.

In order to accurately diagnose this problem and avoid unnecessary healthcare costs a well-defined method of diagnosis remains of primary importance. While no “gold-standard” exists, right heart catheterization or indirect measurement of ejection fraction via radionuclide scanning or echocardiography prove to be reliable diagnostic tests. However, lack of immediate availability and cost make these studies prohibitive in the ED setting. As a result, an ED diagnosis of heart failure is often based on history and physical exam findings along with ancillary tests such as chest radiography and electrocardiography and more recently serum natriuretic peptide (BNP or proBNP) measurements.

### **Emergency Department Diagnosis of Heart Failure**

Traditional history and physical examination findings have important shortcomings.<sup>8</sup> Despite a high specificity for the presence of elevated filling pressures, jugular venous distention

and a third heart sound have sensitivities of only 30% and 24% respectively.<sup>18, 19</sup> Alternatively the Valsalva maneuver can improve the sensitivity of physical examination for detection of left ventricular dysfunction in a highly selected group of patients. However, this requires stable, cooperative patients that are able to hold their breath.<sup>20</sup> Other signs and symptoms of fluid overload such as lower extremity edema and dyspnea again raise the suspicion of heart failure, but their lack of sensitivity makes them poor screening tools.<sup>19</sup> In addition, chest radiography and electrocardiography are often inaccurate. Twenty percent of cardiomegaly noted on echocardiogram is missed on chest radiograph.<sup>21</sup> Pulmonary congestion can be minimal or absent in patients with significantly elevated pulmonary artery wedge pressures.<sup>22</sup> In a recent study, approximately 1 of every 5 ED patients with acute decompensated heart failure did not demonstrate signs of congestion on chest radiography.<sup>23</sup> Standard electrocardiogram results also lack the sensitivity to act as a screening tool.<sup>24, 25</sup>

While pulmonary artery catheterization has been a widely used hemodynamic monitoring device for heart failure in critical care units, its use in the ED is very problematic. Recent studies have raised significant concerns that such catheters do not improve outcome and may have unacceptable complication rates. We are in need of noninvasive measurements of LV filling pressure applicable to both the critical care unit and ED.<sup>26-28</sup>

### **Origin of S3/S4**

The third heart sound (S3) occurs 0.12 to 0.16 seconds after the second heart sound.<sup>29</sup> (Figure 1) Among several proposed theories, the most likely explanation is that excessive rapid filling of a stiff ventricle is suddenly halted, causing vibrations that are audible as the third heart sound. Pathologic states where an S3 is encountered include anemia, thyrotoxicosis, mitral regurgitation, hypertrophic cardiomyopathy, aortic and tricuspid regurgitation and left

ventricular dysfunction.<sup>30</sup> The fourth heart sound (S4) occurs just before the first heart sound in the cardiac cycle. It is produced in late diastole as a result of atrial contraction causing vibrations of the LV muscle, mitral valve apparatus, and LV blood mass.<sup>31</sup> Disease processes that produce an S4 include hypertension, aortic stenosis and regurgitation, severe mitral regurgitation, cardiomyopathy, and ischemic heart disease.<sup>30</sup>

### **Auscultation of the S3 and S4**

Both an S3 and S4 are auscultated in similar fashion. Harvey recommended the “inching” technique as a way to distinguish the often times pathologic S3 and S4 from the physiologic S1 and S2.<sup>32</sup> In both situations the patient is examined in the left lateral recumbent position using the bell of the stethoscope. Starting at the aortic area (where the S2 is the loudest) the examiner “inches” down to the cardiac apex, using the S2 as a reference point. If one encounters an extra sound in diastole, just after the S2, this is an S3 or diastolic gallop. The S3 is generally absent at the base, so that as the examiner moves toward the apex the S3 is encountered.

The opposite maneuver leads to the detection of an S4. Now, the examiner inches from the apex upward to the base. The first heart sound (heard loudest at the apex) is used as a reference because the S4 occurs in early systole, just before S1. If the stethoscope is moved away from the apex, the S4 disappears. In order to distinguish a split S1 from an S3/S4 (both lower frequency sounds than an S1) the examiner places pressure on the bell of the stethoscope. In this situation an S3/S4 will disappear, while a fixed split S1 will remain.

### **Significance of S3 and S4 Detection in Heart Failure**

Identification of an S3/S4 by routine auscultation can be problematic. In the previously mentioned studies that suggest a low incidence of S3 detection in heart failure, it is possible that the physicians may have been unable to detect a sound that was truly present. Recent studies

indicate that physicians are becoming less proficient at performing the physical examination, and physicians in residency programs have been shown to have poor cardiac auscultatory skills.<sup>33-37</sup> Furthermore, inter-observer agreement of S3 detection is poor, with board-certified cardiologists having no better agreement than house staff.<sup>38-40</sup> Exacerbating the difficulty of S3/S4 detection is that the ED environment is often loud, patients have many confounding illnesses such as COPD and obesity that make detection difficult, and the patients may not tolerate being placed in the ideal examining position (recumbent or left lateral decubitus) because of their dyspnea and/or orthopnea. Thus, while detection of an S3/S4 may be useful as a diagnostic and prognostic tool in ED patients with dyspnea, the traditional method of auscultation is less than ideal.

The overall prevalence of an electronically detected S3 is 10% among asymptomatic adults and its detection in older adults may be highly specific for cardiac pathology. While detection of an S3 can be “normal” in adolescents and young adults, its detection after the age of 40 is considered abnormal.<sup>30, 41-43</sup> Traditionally insensitive for LV dysfunction, when detected, an S3 can be very predictive of elevated LV filling pressure. In a study of outpatients referred for cardiac catheterization, the detection of an S3 was the most specific finding of elevated left ventricular end diastolic pressure (95%).<sup>44</sup> Another study also found that the detection of an S3 has a high specificity and positive predictive value in detection of patients with low ejection fractions.<sup>45</sup> Even more importantly, it has been suggested that patients with a detectable S3 have an increased risk of hospitalization and death compared to those patients without a detectable S3.<sup>46-48</sup>

It is not clear whether the presence of an audible S4 is predictive of cardiac disease. While an electronically detected S4 increases in prevalence with increasing age, it may be less common than previously reported.<sup>49</sup> Utilizing phonocardiographic technology available in the

1970's, Spodick and Quarry found the presence of an S4 to be no more common in patients with heart disease than those without.<sup>50</sup> Previous phonocardiographic studies have found a prevalence of S4s from as low as 11%<sup>51</sup> to as high as 75%<sup>52</sup> as well as many values in between.<sup>50, 53-57</sup> These studies may have overestimated the prevalence of S4 when compared to routine auscultation due to the overlapping low frequency sound range of the S4 (10-50Hz) with the typical frequencies of the S1 (30-150 Hz), thus making it difficult to distinguish an S4 from a split S1.<sup>49</sup>

## **New Technologies**

Technology has recently been developed to aid the clinician with bedside detection of an S3 by digitally recording and analyzing heart tones using an electronic stethoscope or other means (Phonocardiograph and Heart Energy Signature software, Biosignetics, Inc., Exeter, New Hampshire; Inovise Medical, Inc., Portland, Oregon) These provide unique and valuable information to the examining physician at the bedside about pathologic heart sounds (S3/S4) and murmurs.

One such platform converts complex multi-component non-gaussian heart sounds into simple images. It is based on an application that reads sound, vibration or any other dynamic time-varying data files and processes them to estimate characteristic energy signatures jointly in time and frequency space. This technology allows rapid computation, provides convenient post-processing options and a graphical-user interface. The *Phonocardiograph Monitor* displays and records heart sounds from an electronic stethoscope, as well as abnormal sound grades, intensity, and pitch (Figure 2). The *Heart Energy Signature* system allows instant visual detection of abnormalities and detailed characterization of power and pitch variation for each sound

component by representing the heart sound as a visual image and obtaining quantitative characteristics of power and pitch variation in time (Figure 3). The printout can be displayed on a laptop.

The Audicor (Inovise Medical, Inc., Portland, OR) is a portable acoustic cardiograph integrated with a standard 12-lead electrocardiogram (Figure 4). Phonocardiographic evidence of heart sounds is determined by a computerized algorithm that reports several different phonocardiographic measures, including the presence of an S3 and S4 gallop, electromechanical activation time (duration from QRS onset to mitral valve closure), and left ventricular systolic time. This method has been previously validated in studies comparing the detection of S3 and S4 to hemodynamic measurements obtained during cardiac catheterization<sup>58</sup> Both V3 and V4 channels are analyzed by the algorithm for the presence of abnormal diastolic heart sounds, using the ECG as a timing marker and frequency content appropriate for the gallops.

Utilizing this system, Collins et al determined the sensitivity of an electronic S3 to be 34% and the specificity to be 93% and found that the presence of an electronically detected S3 in combination with an indeterminate BNP (100-500 pgm/mL) increased the positive likelihood ratio for primary heart failure diagnosis from 1.3 to 2.9 and increased the PPV from 54% to 80%.<sup>59</sup> In a related study, Collins et al documented the electronic presence of an S3 in over 50% of ED patients with the diagnosis of primary heart failure prior to treatment with vasodilators or diuretics. The S3 prevalence was reduced to 29% when heart sounds were analyzed following treatment with diuretics, vasodilators or both. The S4 was similarly decreased after treatment.<sup>60</sup> In a recent meta-analysis, Wang et al found that an auscultated S3 had the largest positive likelihood ratio among physical exam findings (Positive LR, 11; 95%CI, 4.9-25) for accurately detecting heart failure. The likelihood ratio was even higher among those with underlying

pulmonary disease (asthma/COPD) (Positive LR, 57; 95% CI 7.6-425).<sup>8</sup> Additionally, Shapiro and colleagues described a left ventricular dysfunction index which combined S3 and systolic time interval data obtained using the Audicor system. This index, using a cutoff of > 1.87, had 72% sensitivity, 92% specificity, a positive likelihood ratio (LR) of 9.0 and an accuracy of 88% in predicting LV dysfunction. When applied in patients with intermediate BNP levels (100-500 pg/ml) the LR for LV dysfunction increased from 1.1 for BNP alone to 7.1 when the summary index was added.<sup>61</sup> Other preliminary results have shown an improvement in ED physician diagnostic confidence and additive independent prognostic information.<sup>59, 62</sup>

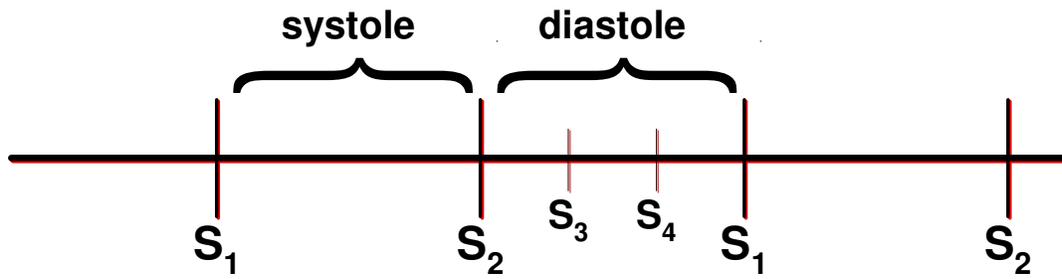
These newer technologies for the phonocardiographic detection of added heart tones should improve significantly our ability to detect abnormal extra heart sounds in the chaotic and noisy ED environment, and may potentially lead to improved diagnostic and prognostic abilities. These tools may also be used to grade the severity of heart failure, track responses to therapeutic interventions or even follow worsening disease.

## **Conclusions**

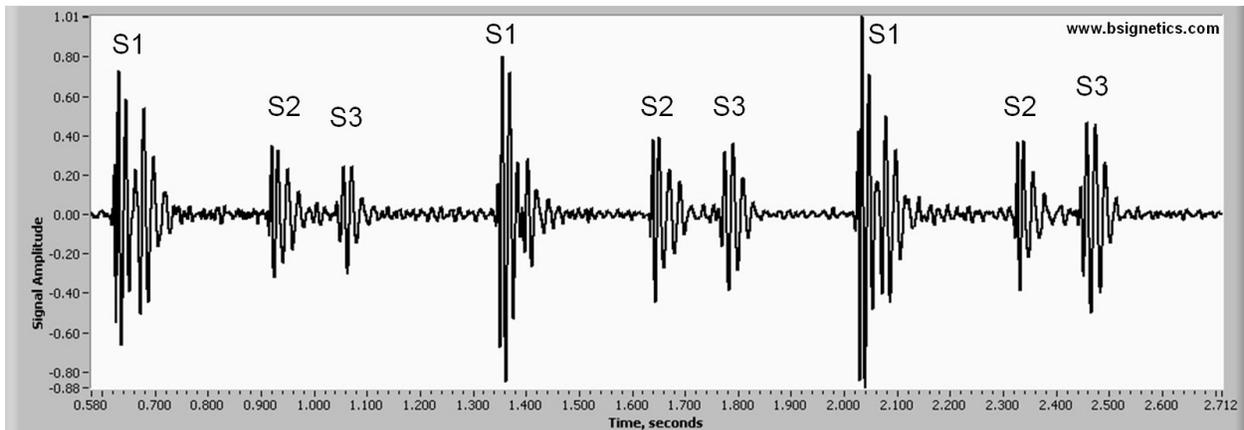
While the S3 gallop may be difficult to detect in the emergency department, its presence has a high specificity and positive likelihood ratio for the presence of heart failure, even among those with underlying pulmonary disease. It can be combined with serum BNP for better diagnostic accuracy. New technologies have been developed to electronically detect the presence of added heart sounds which can be used to help differentiate LV dysfunction from other causes of dyspnea, assess response to therapy, or possibly track worsening severity of disease. The

overall utility and usefulness of these newer technologies in the ED setting needs further study, although preliminary results are promising.

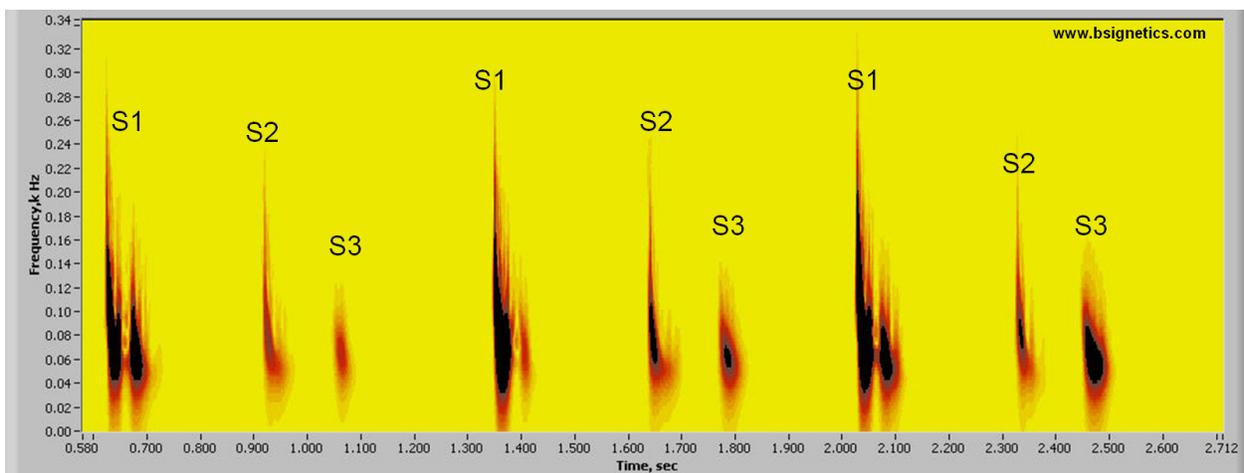
**Figure 1. Location of Heart Sounds in the Cardiac Cycle**



**Figure 2. Phonocardiograph recording of 3 heart beats. Normal S1 and S2 with added S3.**

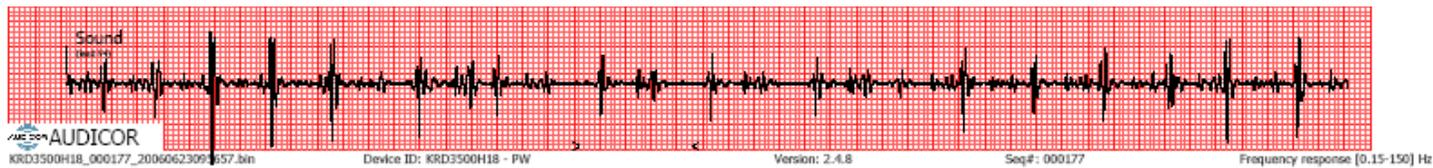
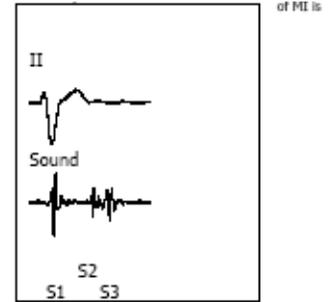


**Figure 3. Heart Energy Signature three heart beats**



- ▣ Audicor finding for 40+ male
- ▣ S3 consistent with LV dysfunction
- ▣ Excluding conditions detected (AFIB, QRSD>140)

Reviewed by: \_\_\_\_\_



#### Figure 4

The Audicor system reports the presence of an S3 (top) and provides a sound tracing (bottom) in this version paired with a standard ECG.

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