Cardiac Hemodynamic Monitoring for the Management of Heart Failure in the Outpatient Setting

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**DESCRIPTION**

A variety of outpatient cardiac hemodynamic monitoring devices are intended to improve quality of life and reduce morbidity for patients with heart failure by decreasing episodes of acute decompensation. Monitors can identify physiologic changes that precede clinical symptoms and thus allow preventive intervention. These devices operate through various mechanisms, including implantable pressure sensors, thoracic bioimpedance measurement, inert gas rebreathing, and estimation of left ventricular end diastolic pressure by arterial pressure during Valsalva maneuver.

**OBJECTIVE**

The objective of this policy is to determine whether outpatient hemodynamic monitoring improves the net health outcome in individuals with heart failure.

**BACKGROUND**

**Chronic Heart Failure**

Patients with chronic heart failure are at risk of developing acute decompensated heart failure, often requiring hospital admission. Patients with a history of acute decompensation have the additional risk of future episodes of decompensation, and death. Reasons for the transition from a stable, chronic state to an acute, decompensated state include disease progression, as well as acute events such as coronary ischemia and dysrhythmias. While precipitating factors are frequently not
identified, the most common preventable cause is noncompliance with medication and dietary regimens.¹

**Management**

Strategies for reducing decompensation, and thus the need for hospitalization, are aimed at early identification of patients at risk for imminent decompensation. Programs for early identification of heart failure are characterized by frequent contact with patients to review signs and symptoms with a healthcare provider and with education or adjustment of medications as appropriate. These encounters may occur face-to-face in the office or at home, or cellular or computed technology.²

Precise measurement of cardiac hemodynamics is often employed in the intensive care setting to carefully manage fluid status in acutely decompensated heart failure. Transthoracic echocardiography, transesophageal echocardiography (TEE), and Doppler ultrasound are noninvasive methods for monitoring cardiac output on an intermittent basis for the more stable patient but are not addressed in this policy. A variety of biomarkers and radiologic techniques may be utilized in the setting of dyspnea when the diagnosis of acute decompensated heart failure is uncertain.

A number of novel approaches have been investigated as techniques to measure cardiac hemodynamics in the outpatient setting. It is postulated that real-time values of cardiac output or left ventricular end diastolic pressure (LVEDP) will supplement the characteristic signs and symptoms and improve the clinician’s ability to intervene early to prevent acute decompensation. Four methods are reviewed here: thoracic bioimpedance, inert gas rebreathing, arterial waveform during the Valsalva maneuver, and implantable pressure monitoring devices.

**LVEDP Estimation Methods**

**Pulmonary Artery Pressure Measurement to Estimate LVEDP:** LVEDP can also be approximated by direct pressure measurement of an implantable sensor in the pulmonary artery (PA) wall or right ventricular outflow tract. The sensor is implanted via right heart catheterization and transmits pressure readings wirelessly to external monitors. One device, the CardioMEMS Champion Heart Failure Monitoring System (CardioMEMS, now St. Jude Medical, St. Paul, MN), has approval from FDA for the ambulatory management of heart failure patient. The CardioMEMS device is implanted using a heart catheter system fed through the femoral vein and generally requires patients have an overnight hospital admission for observation after implantation.

**Thoracic Bioimpedance:** Bioimpedance is defined as the electrical resistance of tissue to the flow of current. For example, when small electrical signals are transmitted through the thorax, the current travels along the blood-filled aorta, which is the most conductive area. Changes in bioimpedance, measured during each beat of the heart, are inversely related to pulsatile changes in volume and velocity of blood in the aorta. Cardiac output
is the product of stroke volume by heart rate, and thus can be calculated from bioimpedance. Cardiac output is generally reduced in patients with systolic heart failure. Acute decompensation is characterized by worsening of cardiac output from the patient's baseline status. The technique is alternatively known as impedance +++ and impedance cardiography (ICG).

**Inert Gas Rebreathing:** This technique is based on the observation that the absorption and disappearance of a blood-soluble gas is proportional to cardiac blood flow. The patient is asked to breathe and rebreathe from a rebreathing bag filled with oxygen mixed with a fixed proportion of two inert gases; typically nitrous oxide and sulfur hexafluoride. The nitrous oxide is soluble in blood and is therefore absorbed during the blood’s passage through the lungs at a rate that is proportional to the blood flow. The sulfur hexafluoride is insoluble in blood and therefore stays in the gas phase and is used to determine the lung volume from which the soluble gas is removed. These gases and carbon dioxide are measured continuously and simultaneously at the mouthpiece.

**Arterial Pressure During Valsalva to Estimate LVEDP:** Left ventricular end diastolic pressure (LVEDP) is elevated in the setting of acute decompensated heart failure. While direct catheter measurement of LVEDP is possible for patients undergoing cardiac catheterization for diagnostic or therapeutic reasons, its invasive nature precludes outpatient use. Noninvasive measurements of LVEDP have been developed based on the observation that arterial pressure during the strain phase of the Valsalva maneuver may directly reflect the LVEDP. Arterial pressure responses during repeated Valsalva maneuvers can be recorded and analyzed to produce values that correlate to the LVEDP.

**REGULATORY STATUS**

**Noninvasive LVEDP Measurement Devices**

In June 2004, the “VeriCor®” (CVP Diagnostics, Boston, MA) noninvasive LVEDP measurement device was cleared for marketing by FDA through the 510(k) process. FDA determined that this device was substantially equivalent to existing devices for the following indication:

“The VeriCor is indicated for use in estimating non-invasively, left ventricular end-diastolic pressure (LVEDP). This estimate, when used along with clinical signs and symptoms and other patient test results, including weights on a daily basis, can aid the clinician in the selection of further diagnostic tests in the process of reaching a diagnosis and formulating a therapeutic plan when abnormalities of intravascular volume are suspected. The device has been clinically validated in males only. Use of the device in females has not been investigated.”

FDA product code: DXN.
Thoracic Bioimpedance Devices
Multiple thoracic impedance measurement devices that do not require invasive placement have been cleared for marketing by the U.S. Food and Drug Administration (FDA) through the 510(k) process because FDA determined that this device was substantially equivalent to existing devices for use for peripheral blood flow monitoring. Table 1 includes a representative list of devices but is not meant to be comprehensive (FDA product code: DSB).

Table 1. Noninvasive Thoracic Impedance Plethysmography Devices

<table>
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<th>Device</th>
<th>Manufacturer</th>
<th>Year of FDA Clearance</th>
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<tr>
<td>TEOBC® (Thoracic Electrical Bioimpedance Cardiac Output)</td>
<td>Hemo Sapiens Inc. (Irvine, CA)</td>
<td>1996</td>
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<tr>
<td>BioZ® Thoracic Impedance Plethysmograph</td>
<td>SonoSite (Bothell, WA)</td>
<td>1997</td>
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<td>IQ™ System Cardiac Output Monitor</td>
<td>Renaissance Technology (Newtown, PA)</td>
<td>1998</td>
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<tr>
<td>Sorba Steorra® Non-Invasive Impedance Cardiography</td>
<td>Sorba Medical Systems Inc. (Milwaukee, WI)</td>
<td>2002</td>
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<tr>
<td>Zoe® Fluid Status Monitor</td>
<td>Noninvasive Medical Technologies LLC (Las Vegas, NV)</td>
<td>2004</td>
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<tr>
<td>Cheetah NICOM® system</td>
<td>Cheetah Medical Inc. (Tel Aviv, Israel)</td>
<td>2008</td>
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<td>Physioflow® Signal Morphology-based Impedance Cardiography (SM-ICG™)</td>
<td>Vascom Inc., now Neumedix Inc. (Bristol, PA)</td>
<td>2008</td>
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<tr>
<td>ReDS™ Wearable System</td>
<td>Sensible Medical Innovations (Philadelphia, PA)</td>
<td>2015</td>
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In 2007, the NEXTFIN HD Continuous Noninvasive Hemodynamic Monitor (BYMEYE B.V., now Edwards Lifesciences, Irvine, CA) uses an inflatable finger cuff with a built-in photoelectric plethysmograph, which calculates estimated cardiac output from continuous blood pressure monitoring; the monitor was cleared by FDA through the 510(k) process in 2007. Other noninvasive monitors that derive cardiac output estimates from measured parameters exist, but not all are designed to be used in the outpatient setting.

In addition, several manufacturers market thoracic impedance measurement devices integrated into implantable cardiac pacemakers, cardioverter defibrillator devices, and cardiac resynchronization therapy devices.

Inert Gas Rebreathing Devices
In March 2006, the "Innocor®" (Innovision, Denmark) inert gas rebreathing device was cleared for marketing by FDA through the 510(k) process. FDA determined that this device was substantially equivalent to existing devices for use in computing blood flow. FDA product code: BZG.

Implantable Pulmonary Artery Pressure Measurement Devices
In May 2014, FDA approved the CardioMEMS™ Champion Heart Failure Monitoring System (CardioMEMS, now St. Jude Medical, St. Paul, MN) through the PMA process. This device consists of an implantable PA sensor, which is implanted in the distal PA, a transvenous delivery system, and an electronic sensor that processes signals from the
implantable PA sensor and transmits PA pressure measurements to a secure database.3 The device originally underwent FDA review in 2011, at which point the Circulatory System Device Panel decided that there was not reasonable assurance that the discussed monitoring system is effective, particularly in certain subpopulations, although most panel members agreed that that the discussed monitoring system is safe for use in the indicated patient population.4

Several additional devices that monitor cardiac output through measurements of pressure changes in the PA or right ventricular outflow tract have been investigated in the research setting but have not received FDA approval. These include the Chronicle® implantable continuous hemodynamic monitoring device (Medtronic Inc., Minneapolis, MN), which includes a sensor implanted in the right ventricular outflow tract and, and the ImPressure® device (Remon Medical Technologies, Caesara, Israel), which includes a sensor implanted in the PA.

Note: This policy only addresses use of these techniques in ambulatory care and outpatient settings.

**POLICY**
In the ambulatory care and outpatient setting, cardiac hemodynamic monitoring for the management of heart failure utilizing thoracic bioimpedance, inert gas rebreathing, arterial pressure during Valsalva maneuver, and implantable direct pressure monitoring of the pulmonary artery is considered experimental / investigational.

**RATIONALE**
The most recent literature search for this policy was conducted with a search of the MEDLINE database for the period through March 23, 2017.

Evaluation of a diagnostic technology typically focuses on the following 3 characteristics: (1) technical performance; (2) diagnostic parameters (sensitivity, specificity, and positive and negative predictive value) in different populations of patients; and (3) demonstration that the diagnostic information can be used to improve patient outcomes. Additionally, when considering invasive monitoring, any improvements in patient outcomes must be outweighed by surgical and device-related risks associated with implantable devices. The review of evidence is limited to studies on the effect on patient outcomes when such data are available.

For the first indication, because we have direct evidence from a large randomized controlled trial (RCT), we will focus on it and assess the evidence it provides on clinical utility. For indications 2, 3, and 4, we will assess the evidence using the 3 characteristics outlined above.

**Implantable Direct Pulmonary Artery Pressure Measurement Methods**
RCTs have directly compared management of heart failure using pulmonary artery pressure measurements to standard management.
CardioMEMS Device
The CHAMPION (CardioMEMS Heart Sensor Allows Monitoring of Pressure to Improve Outcomes in NYHA Class III Patients) Trial was a prospective, single-blind RCT conducted at 64 centers in the United States evaluating an implanted, passive, wireless, pulmonary artery pressure monitor for the ambulatory management of heart failure patients. The CHAMPION study enrolled 550 patients who had at least 1 previous hospitalization for heart failure in the past 12 months and were classified as having New York Heart Association (NYHA) class III heart failure for at least 3 months. All enrolled patients received the CardioMEMS pulmonary artery radiofrequency pressure sensor monitor and standard of care heart failure disease management following American College of Cardiology and American Heart Association guidelines along with local disease management programs. Patients were randomized in a 1:1 ratio to the treatment group (n=270), in which physicians used data from the pulmonary artery pressure sensor in patient management, or to the control group (n=280), in which physicians did not incorporate pulmonary artery pressure sensor data into patient management. All patients took daily pulmonary artery pressure readings but were masked to their group assignments for the first 6 months.

The trial’s primary efficacy outcome was the rate of heart failure–related hospitalizations in the 6 months after implantation. The primary safety outcomes were device-related or system-related complications and pressure-sensor failures. The investigators reported a statistically significant reduction in readmissions for heart failure at 6 months (by 30%) in the treatment group (n=83) compared with the control group (n=120) (hazard ratio [HR], 0.70; 95% confidence interval [CI], 0.60 to 0.84; p<0.001) and over the entire randomized follow-up (mean, 15 months) (153 hospitalizations vs 253 hospitalizations, respectively; HR=0.64; 95% CI, 0.55 to 0.75; p<0.001). The primary safety outcome (freedom from device-related complications) was met by 98.6% of patients, with no occurrences of pressure-sensor failure. However, 15 adverse events occurred, including 8 that were device-related and 7 that were procedure-related. Additionally, length of stay for these hospitalizations was significantly shorter in the treatment group (2.2 days) compared with the control group (3.8 days; p=0.02). There were improvements in the secondary outcomes of mean pulmonary pressure and quality of life at 6 months. There were 15 deaths in the treatment group and 26 deaths in the control group at 6 months (HR=0.77; 95% CI, 0.40 to 1.51; p=0.45).

In the Summary of Safety and Effectiveness Data for the CardioMEMS 2014 application, the U.S. Food and Drug Administration (FDA) noted that “trial conduct included subject-specific treatment recommendations sent by nurses employed by the CardioMEMS to the treating physicians. These subject-specific recommendations were limited to subjects in the treatment arm of the study. The possible impact of nurse communications was determined to severely limit the interpretability of the data in terms of effectiveness.” In response to FDA, the manufacturer continued to follow all patients implanted with the device during an open-access period, in which all patients were managed with pulmonary artery pressure monitoring, and no nurse communication occurred. Follow-up data were available for 347 patients. For these patients, the following comparisons in heart failure–related hospitalization rates were reported to attempt to ensure that outcomes with the CardioMEMS device during the open-access period (“Part 2”) were similar to those in the randomized period (“Part 1”):

- Former Control vs Control: “To determine whether the HFR [heart failure rate] hospitalization rate was lower in the Former Control group than the Control group, when
physicians of Former Control patients received access to PA [pulmonary artery] pressures (neither had nurse communications).”

- Former Treatment to Treatment: “To evaluate whether HFR hospitalization rates remain the same in subjects whose physician’s access to PA pressures remained unchanged, but no longer received nurse communications.”
- Former Control to Former Treatment: “To demonstrate that the rates of HFR hospitalizations were similar during Part 2 when both groups were managed in an identical fashion (access to PA pressure and no nurse communications).”
- “Change in HFR Hospitalization Rates in the Control group (Part 2 vs. Part 1) compared to the Change in HFR Hospitalization Rates in the Treatment Group (Part 2 vs. Part 1): To demonstrate that the magnitude of change in HFR hospitalization rates after the transition from Control to Former Control (Part 1 vs. Part 2, initiation of physician access to PA pressures in Part 2) was greater than the magnitude of change in HFR hospitalization rates after the transition from Treatment to Former Treatment (Part 1 vs. Part 2, no change in physician access to PA pressure).”

FDA concluded that these longitudinal analyses indicated that heart failure hospitalization rates in former control patients in Part 2 of the study decreased to levels comparable with the heart failure hospitalization rates in Treatment group patients whose pulmonary artery pressures were available throughout the trial.

A follow-up report on the CHAMPION trial was published in 2016.7 It included data on 13 months of open-label follow-up for 347 (63%) of the original 550 randomized patients. For patients originally randomized to the control group, information from the monitoring device was available during this phase. The rate of hospitalizations was significantly lower in this group (HR=0.52; 95% CI, 0.40 to 0.69; p<0.001) compared to the period when no monitoring information was available.

In 2015, Kranzke et al published a subgroup analysis of the CHAMPION trial evaluating outcomes for heart failure patients with chronic obstructive pulmonary disease (COPD).8 Of the total trial population, 187 were classified as having COPD; these patients were more likely to have coronary artery disease and a history of myocardial infarction, diabetes, and atrial fibrillation. COPD-classified patients in the intervention group had lower rates of heart failure hospitalization (0.55) than those in the control group (0.96; HR=0.59; 95% CI, 0.44 to 0.81; p<0.001). Rates of respiratory hospitalizations were also lower in COPD-classified patients in the intervention group (0.12 vs 0.31; HR=0.38; 95% CI, 0.21 to 0.71; p=0.002). Rates of respiratory hospitalizations did not differ significantly between intervention and control group patients who did not have COPD.

Other Implantable Devices
Stevenson et al (2010) and Bourge et al (2008) reported on the Chronicle Offers Management to Patients with Advanced Signs and Symptoms of Heart Failure (COMPASS-HF) randomized trial.9,10 It evaluated outcomes on 274 patients implanted with a Medtronic hemodynamic monitoring system. Patients enrolled in the trial were stabilized NYHA class III or IV heart failure patients who had at least 1 heart failure–related event within the 6 months before enrollment. Left ventricular ejection fraction was not a criterion. Similar to the CHAMPION trial, all patients were implanted with the monitoring device and received standard heart failure disease treatment.
during the first 6 months postimplantation. One-half of the patients were randomized to incorporate pressure monitoring data into heart failure management, while information from the other half of patients was not used in treatment decisions. The authors of this article reported 100 (38%) of 261 patients from both treatment groups had heart failure–related events during the 6 months of follow-up, despite weight-guided management. Separate reports on heart failure events by treatment group were not provided. Heart failure event risk increased with higher readings of chronic 24-hour estimated pulmonary artery pressure and at a diastolic pressure of 18 mm Hg, event risk was 20% and increased to 34% at 25 mm Hg and to 56% at 33 mm Hg. While pressure readings correlated with event risk, the authors noted optimal filling pressures and needed surveillance for event avoidance have not been established. The Medtronic Chronicle Hemodynamic Monitor was denied FDA approval in March 2007.

In 2011, Adamson et al reported on the Reducing Decompensation Events Utilizing Intracardiac Pressures in Patients With Chronic Heart Failure (REDUCEhf) trial, which evaluated an implantable cardioverter defibrillator (ICD) coupled with an implantable hemodynamic monitoring (IHM) system. The REDUCEhf trial was a prospective, randomized, multicenter, single-blinded trial of 400 patients with NYHA class II or III symptoms who were hospitalized for heart failure within the past 12 months and qualified for an ICD. The trial had expected to enroll 1300 patients, but after ICD lead failures had been reported in other studies, enrollment was limited to 400 patients. After the ICD was placed, an IHM sensor was implanted in the right ventricle. Similar to the COMPASS-HF and CHAMPION trials (previously discussed), the treatment group of 202 patients received heart failure management that incorporated pressure monitoring information from the IHM compared with the control group of 198 patients that did not. After 12 months of follow-up, rates of heart failure hospitalizations, emergency department visits, and urgent clinic visits did not differ between groups (HR=0.99; 95% CI, 0.61 to 1.61; p=0.98). While the trial was underpowered to detect differences in these events because of limited enrollment, there were no trends favorable to the monitoring group to suggest that the lack of difference was due to inadequate power.

Section Summary: Implantable Direct Pulmonary Artery Pressure Measurement Methods
There are several RCTs of implantable hemodynamic monitoring systems. One of these trials (CHAMPION trial) used an FDA-approved monitor and was powered to report on clinical outcomes. This trial reported a decrease in hospitalizations for patients using the monitor as part of heart failure management compared with usual care. However, this trial had some methodologic limitations, one of which was the lack of double-blinding. While patients were blinded and efforts to maintain masking were undertaken, the clinicians were not blinded to treatment assignment. The unblinded clinicians were presumably also making decisions on whether to hospitalize patients, and these decisions may have been influenced by knowledge of treatment assignment. A second limitation was the unequal intensity of treatment between groups, with the implantable monitor group having greater frequency of contact with study nurses. Further high-quality trials are needed to determine whether health outcomes are improved.

Noninvasive Thoracic Bioimpedance/Impedance Cardiography
Technical Performance
A number of early studies evaluated the accuracy of thoracic bioimpedance compared with other methods of cardiac output measurements in the inpatient and outpatient settings. In 2004, the
Agency for Healthcare Research and Quality published a technology assessment on thoracic bioimpedance, which concluded that limitations in available studies did not permit meaningful conclusions on the accuracy of thoracic bioimpedance compared with other hemodynamic parameters.2

A number of small case series have reported variable results on the relation between measurements of cardiac output determined by thoracic bioelectric impedance and thermodilution techniques. For example, Belardinelli et al (1996) compared the use of thoracic bioimpedance, thermodilution, and the Fick method to estimate cardiac output in 25 patients with documented coronary artery disease and a previous myocardial infarction.12 There was a high degree of correlation between cardiac output as measured by thoracic bioimpedance and other invasive measures. Shoemaker et al (1994) reported on a multicenter trial of thoracic bioimpedance compared with thermodilution in 68 critically ill patients.13 Again, the changes in cardiac output, as measured by thoracic bioimpedance tracked closely those measured by thermodilution. By contrast, Sageman and Amundson (1993) reported a poor correlation between thermodilution and bioimpedance for postoperative monitoring in a study of 50 patients post–coronary artery bypass surgery, primarily due to the postoperative distortion of patient anatomy and the presence of endotracheal, mediastinal, and chest tubes.14 In a study of 34 patients undergoing cardiac surgery, Doering et al (1995) also found poor agreement between thoracic bioimpedance and thermodilution in the immediate postoperative period.15

Amir et al (2013) compared a noninvasive thoracic base wave impedance monitor (ReDS), which provides measurement of patient lung fluid content, with chest computed tomography for measurement of total lung fluid in 16 patients with acute decompensated heart failure and 15 controls without heart failure.16 The fluid content measurements correlated highly (intraclass correlation coefficient [ICC], 0.90; 95% CI, 0.80 to 0.95). The absolute mean difference between the measurement of fluid content with the 2 methods was 3.8% (SD=2.2%).

**Diagnostic Accuracy**

Several studies have assessed the association between thoracic bioimpedance measurements and heart failure–related outcomes.

In a subanalysis of 170 subjects from the Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE), a multicenter randomized trial to assess pulmonary artery catheter-guided therapy in patients with advanced heart failure, Kamath et al (2009) compared cardiac output estimated by the BioZ device with subsequent heart failure death or hospitalization and to directly measured hemodynamics from right heart catheterization in a subset of patients (n=82).17 There was modest correlation between impedance cardiography (ICG) and invasively measured cardiac output (r range, 0.4-0.6), but no significant association between ICG measurements and subsequent heart failure death or hospitalization.

Packer et al (2006) reported on use of ICG to predict decompensation in patients with chronic heart failure.18 In this study, 212 stable patients with heart failure and a recent episode of decompensation underwent serial evaluation and blinded ICG testing every 2 weeks for 26 weeks and were followed for the occurrence of death or worsening heart failure requiring hospitalization or emergent care. During the study, 59 patients experienced 104 episodes of decompensated heart failure, including 16 deaths, 78 hospitalizations, and 10 emergency department visits.
composite score of 3 ICG parameters was a predictor of an event during the next 14 days (p<0.001). Patients noted to have a high-risk composite score at a visit had a 2.5 times greater likelihood of a near-term event, and those with a low-risk score had a 70% lower likelihood compared with patients at intermediate risk.

In 2011, Anand et al reported on results for the Multi-Sensor Monitoring in Congestive Heart Failure (MUSIC) Study, a nonrandomized prospective trial designed to develop and validate an algorithm for the prediction of acute heart failure decompensation using a clinical prototype of the MUSE system, multisensory system that includes intrathoracic impedance measurements, along with electrocardiographic and accelerometry data. The trial enrolled 543 (206 in the development phase, 337 in the validation phase) patients with heart failure with an ejection fraction less than 40% and a recent heart failure admission, all of whom underwent monitoring for 90 days with the MUSE. There was a high rate of trial dropout: 229 (42% of the total; 92 development, 137 validation) patients were excluded from the analysis, primarily due to withdrawal of consent or failure of the prototype device to function. Subjects were assessed for the development of an acute decompensated heart failure (ADHF) event, which was defined as any of the following: (1) any heart failure–related hospitalization, emergency department or urgent care visit that required administration of intravenous diuretics, inotropes, or ultrafiltration for fluid removal; (2) a change in diuretic directed by the health care provider that included 1 or more of the following: a change in the prescribed diuretic type; an increase in dose of an existing diuretic; or the addition of another diuretic; or (3) an ADHF event for which death was the outcome. Data from the 206 subjects in the development phase were used to generate a multiparameter algorithm to predict outcomes that incorporated fluid index, a breath index, and personalization parameters (age, sex, height, weight). When the algorithm was applied to the validation cohort, it had a sensitivity of 63%, specificity of 92%, and a false-positive rate of 0.9 events per patient-year. The algorithm had an mean advance detection time of 11.5 days, but there was wide variation in this measure, from 2 to greater than 30 days, and performance did not differ significantly from less specific algorithms (eg, based on fluid index alone). The high rate of trial dropout makes it difficult to generalize these results.

Clinical Utility
Amir et al (2016) reported on results for a single-arm study of the ReDS technology in 50 patients recently hospitalized for heart failure. Patients were enrolled after admission for heart failure and were managed according to the American College of Cardiology Foundation/American Heart Association and Heart Failure Society of America guidelines. Patients were also equipped with the ReDS wearable vest, which was worn once a day at home to measure lung fluid content. For 90 days, measurements were sent to the treating physician via a secured website and were not visible to patients. Readings that crossed lower or upper thresholds for absolute values or rates of change resulted in an alert message sent to investigators. Physicians could adjust medication doses, recommend dietary changes, and/or encourage compliance with prescribed therapies based on ReDS readings. After the 90-day ReDS-guided management period of follow-up, patients were followed for an additional 90 days without ReDS measurements. Mean follow-up during the ReDS-guided period was 83 days; it is unclear how many patients completed the post-ReDS period. The authors reported that compliance with taking daily measurements was 95%. The rate of heart failure hospitalizations was lower during the ReDS-guided follow-up compared to post-ReDS period (HR=0.11; 95% CI, 0.01 to 0.88; p=0.04). Interpretation of results is uncertain due to the lack of concurrent control and randomization, short-term follow-
up, large confidence intervals, and lack of clarity about lost-to-follow-up during the post-ReDS period. An RCT comparing ReDS monitoring with standard of care is ongoing and expected to finish in September 2017.

Section Summary: Noninvasive Thoracic Bioimpedance/Impedance Cardiography
The evidence on thoracic bioimpedance devices consists of nonrandomized studies that correlate measurements with other measures of cardiac function and studies that use bioimpedance measurement as part of an algorithm to predict future heart failure events. One single-arm study was identified that evaluated the effects on patient outcomes from use of thoracic bioimpedance measurements in managing heart failure. RCTs comparing heart failure management using thoracic bioimpedance to standard management are needed to evaluate effect on patient outcomes. We did not construct chain of evidence on the clinical utility of thoracic bioimpedance devices because it is unclear how these devices will improve patient outcomes.

Inert Gas Rebreathing
Technical Performance and Diagnostic Accuracy
Inert gas rebreathing has been used as a research tool for many years. Hassan et al (2017) compared 4 methods of measuring cardiac output, including IGR, in 97 patients with heart failure and reduced ejection fraction. The intraobserver variability of IGR was measured using the ICC calculated on repeated measurements in 30 patients; the selection criteria were not described. The ICC was 0.94. Cardiac output indexed to body surface area was significantly but modestly correlated between IGR and cardiac magnetic resonance imaging (r=0.7; p<0.001) as well as IGR and cardiac catheterization (r=0.6; p<0.001) and significantly correlated between IGR and echocardiography (r=0.4; p<0.001).

Clinical Utility
No studies were identified that determined how use of inert gas rebreathing measurements is associated with changes in patient management or evaluated effects on patient outcomes.

Section Summary: Inert Gas Rebreathing
The evidence on IGR measurement devices consists of nonrandomized studies that correlate IGR measurements with other measures of cardiac output. No studies were identified that determined how use of IGR measurements in managing heart failure affects patient outcomes. We did not construct chain of evidence on the clinical utility of IGR measurement devices because it is unclear how these devices will improve patient outcomes.

Noninvasive Left Ventricular End Diastolic Pressure Estimation Methods
Technical Performance and Diagnostic Accuracy
Studies have shown a high correlation between invasive and noninvasive measurement of left ventricular end diastolic pressure (LVEDP). For example, McIntyre et al (1992) reported a comparison of pulmonary capillary wedge pressure (PCWP) measured by right heart catheter and an arterial pressure amplitude ratio during the Valsalva maneuver. The 2 techniques were highly correlated in both stable and unstable patients (R² [coefficient of determination] range, 0.80-0.85). Sharma et al (2002) performed simultaneous measurements of the LVEDP based on 3 techniques in 49 patients scheduled for elective cardiac catheterization: direct measurement of LVEDP (considered the criterion standard), indirect measurement using PCWP, and noninvasively using the VeriCor device. The VeriCor measurement correlated well with the direct measures of
LVEDP ($r=0.86$) and outperformed the PCWP measurement, which had a correlation coefficient of 0.81 compared with the criterion standard. In 2012, Silber et al (2012) reported on finger photoplethysmography during the Valsalva maneuver performed in 33 patients before cardiac catheterization. LVEDP greater than 15 mm Hg was identified by finger photoplethysmography during Valsalva maneuver with 85% sensitivity (95% confidence interval [CI], 54% to 97%) and 80% specificity (95% CI, 56% to 93%).

Clinical Utility
No studies were identified that determined how noninvasive measurements of LVEDP are associated with changes in patient management or evaluated effects on patient outcomes.

Section Summary: Noninvasive LVEDP Estimation Methods
The evidence on noninvasive LVEDP measurement devices consists of nonrandomized studies that correlate noninvasive LVEDP measurements with invasive LVEDP measurements. No studies were identified that determined how use of noninvasive LVEDP measurements in managing heart failure affect patient outcomes. We did not construct chain of evidence on the clinical utility of noninvasive LVEDP measurement devices because it is unclear how these devices will improve patient outcomes.

SUMMARY OF EVIDENCE
For individuals who have heart failure in outpatient settings who receive hemodynamic monitoring with an implantable pulmonary artery pressure sensor device, the evidence includes randomized controlled trials (RCTs). Relevant outcomes are overall survival, symptoms, functional outcomes, quality of life, morbid events, hospitalizations, and treatment-related morbidity. One implantable pressure monitor, the CardioMEMS device, has U.S. Food and Drug Administration approval. Using the CardioMEMS device, the CHAMPION RCT reported that use of pulmonary artery pressure readings reduced heart failure–related hospitalizations, but this trial was subject to several potential biases. It was single-blinded, with treating clinicians aware of group assignment. Treating clinicians also made decisions on whether to hospitalize patients, which may have been influenced by knowledge of group assignment. Also, patients in the monitoring group received detailed care recommendations from a study nurse, while patients in the control group did not. Further high-quality RCTs are needed to corroborate whether hospitalizations are reduced by use of an implantable pulmonary artery pressure monitor. The evidence is insufficient to determine the effects of the technology on health outcomes.

For individuals who have heart failure in outpatient setting who receive hemodynamic monitoring by thoracic impedance, with inert gas rebreathing, or of arterial pressure during the Valsalva maneuver, the evidence includes uncontrolled prospective studies and case series. Relevant outcomes are overall survival, symptoms, functional outcomes, quality of life, morbid events, hospitalizations, and treatment-related morbidity. There is a lack of RCT evidence evaluating whether use of these technologies improves health outcomes over standard active management of heart failure patient. The case series have reported physiologic measurement-related outcomes and/or associations between monitoring information and heart failure exacerbations, but do not provide definitive evidence on device efficacy. The evidence is insufficient to determine the effects of the technology on health outcomes.
PRACTICE GUIDELINES AND POSITION STATEMENTS
American College of Cardiology Foundation and American Heart Association
The 2013 ACCF/AHA Guidelines for the Management of Heart Failure offers no recommendations for use of ambulatory monitoring devices.30,31

National Institute for Health and Clinical Excellence
The 2010 update of the National Institute for Health and Clinical Excellence clinical guideline on chronic heart failure management does not include outpatient hemodynamic monitoring as a recommendation.32 This guidance is under review and update and is expected in August 2018.

In 2013, NICE issued guidance on the insertion and use of implantable pulmonary artery pressure monitors in chronic heart failure.33 The recommendations concluded that “Current evidence on the safety and efficacy of the insertion and use of implantable pulmonary artery pressure monitors in chronic heart failure is limited in both quality and quantity.”

U.S. PREVENTIVE SERVICES TASK FORCE RECOMMENDATIONS
Not applicable.

ONGOING AND UNPUBLISHED CLINICAL TRIALS
Some currently unpublished trials that might influence this policy are listed in Table 2.

Table 2. Summary of Key Trials

<table>
<thead>
<tr>
<th>NCT No.</th>
<th>Trial Name</th>
<th>Planned Enrollment</th>
<th>Completion Date</th>
</tr>
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<tbody>
<tr>
<td>Ongoing</td>
<td>Sensible Medical Innovations (Noninvasive) Lung fluid Status Monitor Allows rEducing Readmission Rate of Heart Failure Patients- a Randomized Controlled Study (SMILE)</td>
<td>380</td>
<td>Sep 2017</td>
</tr>
<tr>
<td>Unpublished</td>
<td>Left Atrial Pressure Monitoring to Optimize Heart Failure Therapy Study</td>
<td>486</td>
<td>Apr 2015 (completed)</td>
</tr>
<tr>
<td></td>
<td>Prevention of Heart Failure Events With Impedance Cardiography Testing (PREVENT-HF)</td>
<td>500</td>
<td>Dec 2012 (unknown)</td>
</tr>
</tbody>
</table>

NCT: national clinical trial.
* Denotes industry-sponsored or cosponsored trial.

CODING
The following codes for treatment and procedures applicable to this policy are included below for informational purposes. Inclusion or exclusion of a procedure, diagnosis or device code(s) does not constitute or imply member coverage or provider reimbursement. Please refer to the member’s contract benefits in effect at the time of service to determine coverage or non-coverage of these services as it applies to an individual member.

CPT/HCPCS
93701 Bioimpedance-derived physiologic cardiovascular analysis
93799 Unlisted cardiovascular service or procedure
C9741 Right heart catheterization with implantation of wireless pressure sensor in the pulmonary artery, including any type of measurement, angiography, imaging supervision, interpretation, and report

- There is a specific CPT code for bioimpedance: 93701
- Inert gas rebreathing measurement and left ventricular end diastolic pressure should be reported using the unlisted code: 93799.
- There is no specific CPT code for implantable direct pressure monitoring of the pulmonary artery. The unlisted code 93799 would be used.

**DIAGNOSES**
Experimental / investigational for all diagnoses related to this policy.

**REVISIONS**

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<tr>
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<td>09-10-2010</td>
<td>Title revised:&lt;br&gt;From: &quot;Thoracic Bioimpedance as a Measurement of Cardiac Hemodynamics in the Ambulatory Care - Outpatient Setting&quot; To: &quot;Cardiac Hemodynamic Monitoring for the Management of Heart Failure in the Outpatient Setting&quot;&lt;br&gt;In Policy section:&lt;br&gt;Added arterial pressure/Valsalva and implantable direct pressure monitoring of the pulmonary artery as mechanisms for cardiac hemodynamic monitoring for the management of heart failure in the outpatient setting.&lt;br&gt;In Coding section:&lt;br&gt;Added CPT Code: 93799&lt;br&gt;Updated wording for CPT Code: 93701&lt;br&gt;Description section updated.&lt;br&gt;Rationale section added.&lt;br&gt;References section updated.</td>
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<tr>
<td>03-07-2011</td>
<td>In Coding section:&lt;br&gt;Removed CPT codes: 0104T, 0105T</td>
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REFERENCES


**Other References**