The CardioMEMS™ HF System is the first and only FDA-approved heart failure monitor proven to significantly reduce heart failure hospital admissions and improve quality of life in New York Heart Association (NYHA) Class III heart failure patients.1

When used by clinicians to manage heart failure, the CardioMEMS HF System is:

- Safe and reliable — demonstrated 98.6% freedom from device- or system-related complications1
- Clinically proven — reduced heart failure admissions by 33%1 and all-cause 30-day readmissions by 58%2
- Proactive and personalized — patient management through direct monitoring of PA pressure and titration of medications

Traditional physiologic markers in the development of acute decompensation in patients suffering from heart failure such as intrathoracic impedance, weight, blood pressure and symptoms are late and unreliable,3,4 with only moderate sensitivity and specificity.5-7 Large, randomized, controlled studies using telemonitoring of these indirect markers have failed to demonstrate a reduction in heart failure hospitalizations.3,4,8 This clinical compendium summarizes key studies demonstrating the safety and effectiveness of the CardioMEMS HF System.

What’s New since the Last Update of May 2016?


Schmier JK, Ong KL and Fonarow GC. Cost-Effectiveness of remote cardiac monitoring with the CardioMEMS Heart Failure System. Clinical Cardiology. 2017;40:430-436.


Pre-CHAMPION

VERDEJO HE, CASTRO PF, CONCEPCION R, FERRADA MA, ALFARO MA, ALCAINO ME, DECK CC, BOURGE RC: COMPARISON OF A RADIOFREQUENCY-BASED WIRELESS PRESSURE SENSOR TO SWAN-GANZ* CATHETER AND ECHOCARDIOGRAPHY FOR AMBULATORY ASSESSMENT OF PULMONARY ARTERY PRESSURE IN HEART FAILURE.


The CardioMEMSTM HF System monitors PA pressure measurements from a sensor implanted into the PA. The safety and accuracy of the CardioMEMSTM PA Sensor has been demonstrated in previous studies.9,10 Systolic and diastolic PA pressures were significantly correlated between the CardioMEMSTM PA Sensor and traditional Swan-Ganz catheter measurements and between the CardioMEMSTM PA Sensor and standard echocardiography.9,10

CASTRO PF, CONCEPCION R, BOURGE RC, MARTINEZ A, ALCAINO M, DECK C, FERRADA M, ALFARO M, PERRONE S: A WIRELESS PRESSURE SENSOR FOR MONITORING PULMONARY ARTERY PRESSURE IN ADVANCED HEART FAILURE: INITIAL EXPERIENCE.


Device implantation was simple and the sensor accurately measured pulmonary artery pressure (PA pressure).

No complications were observed and there was no evidence of PA thrombosis at 60 days. Diuretic and vasodilator doses were increased and the patient improved without further heart failure-related hospitalization.


J Card Fail. 2010;17:3-10.

The CHAMPION clinical trial investigated the safety and clinical efficacy of the CardioMEMSTM HF System and established this management strategy as a new paradigm for the medical management of patients with symptomatic heart failure.

ABRAHAM WT, ADAMSON PB, HASAN A, BOURGE RC, PAMBOKIAN SV, AARON MF, RAVAL NY: SAFETY AND ACCURACY OF A WIRELESS PULMONARY ARTERY PRESSURE MONITORING SYSTEM IN PATIENTS WITH HEART FAILURE.


The safety and accuracy of the CardioMEMSTM PA Sensor have been demonstrated in previous studies.9,10 Systolic and diastolic PA pressures were significantly correlated between the CardioMEMSTM PA Sensor and traditional Swan-Ganz catheter measurements and between the CardioMEMSTM PA Sensor and standard echocardiography.9,10

A feasibility study reported the safe and successful implantation of the CardioMEMSTM PA Sensor in a clinical setting with no serious device-related events (n = 17).10

CHAMPION

WIRELESS PULMONARY ARTERY HAEMODYNAMIC MONITORING IN CHRONIC HEART FAILURE: A RANDOMISED CONTROLLED TRIAL.

Abraham, et al. The Lancet. 2011.1

• The aim of this randomized, multicenter, single-blind, controlled study was to evaluate the safety of the system and the efficacy of PA pressure-guided therapy on heart failure hospitalizations.
  – NYHA Class III heart failure patients irrespective of left ventricular ejection fraction and who had been hospitalized for heart failure within the past 12 months were implanted with the CardioMEMSTM PA Sensor (n = 550); patients were randomized to either the treatment group (heart failure management guided by PA pressure measurements; n = 270) or the control group (standard of care (SOC) management; n = 280).

• Mean follow-up time was 15 months.

• Both primary safety and efficacy endpoints were met:
  – Patients had a 98.6% freedom from device- or system-related complications (95% confidence interval (CI) 97.3 to 99.4) with no pressure-sensor failures (95% CI 99.3 to 100.0).
  – The rate of heart failure hospitalizations at six months was reduced by 28% in the treatment group (p = 0.0002).

• During the first six months of follow-up, compared to the control group, the treatment group had:
  – A greater reduction in PA pressure (-156 vs. 33 mean area under the curve; p < 0.008).
  – Fewer patients admitted to the hospital for heart failure (20% treatment group vs. 29% control group; p < 0.03).
  – More days alive outside of the hospital (174.4 ± 31.1 vs. 172.1 ± 37.8 days; p < 0.02).
  – Better patient quality of life (45 ± 26 vs. 51 ± 25; p = 0.02 based on Minnesota Living with Heart Failure Questionnaire).

1. The aim of this randomized, multicenter, single-blind, controlled study was to evaluate the safety of the system and the efficacy of PA pressure-guided therapy on heart failure hospitalizations.

2. Patients had a 98.6% freedom from device- or system-related complications (95% confidence interval (CI) 97.3 to 99.4) with no pressure-sensor failures (95% CI 99.3 to 100.0).

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   – Better patient quality of life (45 ± 26 vs. 51 ± 25; p = 0.02 based on Minnesota Living with Heart Failure Questionnaire).
KEY TAKEAWAYS:

- The treatment group required < 1 medication changes per patient per month compared to the control group (9.1 ± 7.4 vs. 3.8 ± 4.5 changes per patient during the first six months of follow-up; p < 0.0001).

- During the entire follow-up (mean 15 months), PA pressure-guided therapy (treatment group) significantly reduced heart failure hospitalizations by 37% compared to the control group (p < 0.0001; Figure 1).

- The treatment group had a lower risk of death or freedom from first heart failure hospitalization during the entire follow-up period compared to the control group (p = 0.0086).

Figure 1. Cumulative heart failure hospitalizations during the entire period of follow-up

SUSTAINED EFFICACY OF PULMONARY ARTERY PRESSURE TO GUIDE ADJUSTMENT OF CHRONIC HEART FAILURE THERAPY (CHAMPION): COMPLETE FOLLOW-UP RESULTS A RANDOMIZED CONTROLLED TRIAL.


- This CHAMPION clinical trial analysis evaluated the impact on heart failure hospitalizations of the introduction of PA pressure monitoring in the control group (n = 170) of patients and continued PA monitoring in the treatment group (n = 177) during the open access (OA) phase of the trial.

- Following completion of the randomized access (RA) period (mean follow-up of 18 months), all patients were managed utilizing PA pressure monitoring with the CardioMEMS™ HF System (mean follow-up of 13 months) and evaluated in a longitudinal analysis.

- New access to PA pressures in the control group resulted in a 48% reduction in heart failure hospitalization rates (0.36 vs. 0.68; hazard ratio (HR) 0.52; 95% CI 0.40 to 0.69; p < 0.0001; Figure 2).

- The low heart failure hospitalization rate in the treatment group during the RA period was maintained in the OA period (0.45 vs. 0.48; HR 0.93; 95% CI 0.70 to 1.22; p = 0.5838; Figure 2).

KEY TAKEAWAYS:

- The longitudinal analysis confirms the effectiveness of the CardioMEMS HF System and supports the findings from the randomized portion of the CHAMPION clinical trial.

- Even after adjustment for longitudinal confounders, new access to PA pressure monitoring for the formerly blinded control group resulted in a significant reduction in heart failure hospitalizations.

Figure 2. Part 1: Randomized Access and Part 2: Open Access

Randomized and Open Access Periods also Led to Significant Reduction in Heart Failure Hospitalization


*Over 31 months, despite termination of sponsor communications.

Preplanned (Prospective) CHAMPION Subgroup Analyses

**EFFECTS OF PA PRESSURE MONITORING ON HFpEF SUBGROUP**

Wireless Pulmonary Artery Pressure Monitoring Guides Management to Reduce Decompensation in Heart Failure With Preserved Ejection Fraction.


- This subanalysis of the CHAMPION clinical trial evaluated the effect of PA pressure-guided therapy with the CardioMEMS™ HF System in NYHA Class III patients with preserved ejection fraction (HFpEF).
- Of the HFpEF patients (n = 119), 62 were randomized to the treatment group (PA pressure-guided therapy) and 57 to the control group (standard of care).

**KEY TAKEAWAY:**

- PA pressure-guided therapy significantly reduced heart failure hospitalizations for HFpEF patients in the treatment group by 50% compared to those in the control group, with an average follow-up time of 30 months (p < 0.0001). Results were associated with a rate of 0.43 events/patient-year in the treatment group vs. 0.86 events/patient-year in the control group (Figure 3).

Prospective Subgroup Analysis: HFpEF Patients Managed with the CardioMEMS™ HF System Show Significant Reduction in Heart Failure Hospitalization

![Figure 3.](image)

**EFFECTS OF PA PRESSURE MONITORING ON HFrEF SUBGROUP, HFpEF SUBGROUP ALREADY ON GDMT**

Pulmonary Artery Pressure–Guided Management of Patients With Heart Failure and Reduced Ejection Fraction.


Initiation of a PA pressure-guided heart failure management strategy, even in heart failure with reduced ejection fraction (HFrEF) patients receiving optimal background medical and device therapy, was able to achieve large, consistent reductions in heart failure hospitalization and mortality in HFrEF patients enrolled in the CHAMPION trial.

**KEY RESULTS:**

Prospective Study Results

- In CHAMPION HFrEF cohort, heart failure hospitalization rates were 28% lower than control (p = 0.0013); mortality was 32% lower, trending toward significance (p = 0.06) at 18 months (Figure 4 and Figure 5).

Prospective Subgroup Analysis: HFrEF Patients Show Significant Reduction in Heart Failure Hospitalization and Strong Trend Towards Improved Survival*

![Figure 4.](image)

**Figure 3.** Cumulative Heart Failure Hospitalizations

- Control Group, HFpEF: Red: Control Group, HFpEF; Green: Treatment Group, HFpEF.
- Days after Implant: 0, 180, 360, 540, 720, 900.
- 50% reduction in Heart Failure Hospitalization: Avg. 18 months of follow-up 50% RR: p = 0.0001.

**Figure 4.** Clinical Outcomes

- Heart Failure Hospitalization Rate: 0.69 (Control) vs. 0.49 (Treatment) with a 28% reduction in Heart Failure Hospitalization (p = 0.0013).
- Mortality Rate: 0.24 (Control) vs. 0.18 (Treatment) with a 32% reduction in Mortality (p = 0.06).

**Figure 5.** Survival Probability

- Kaplan-Meier Survival Analysis:
  - No. at Risk: Control 234, 209, 173, 102, 45, 7, 0; Treatment 222, 202, 161, 105, 62, 7, 0.
  - HR 0.68 (95% CI 0.45-1.02) p = 0.06.
RETROSPECTIVE STUDY DESCRIPTION

This paper also included a retrospective analysis of the CHAMPION HFrEF cohort (n = 456), based on strong indicators for reduced heart failure hospitalization and mortality in the prospective subgroup analysis of HFrEF patients.

This study addresses the hypothesis that hemodynamic-guided care benefits patients even if they are already on maximum GDMT.

Evaluated heart failure hospitalizations and mortality based on patients’ ability to tolerate full GDMT vs. incomplete medical therapy.

KEY RESULTS:

- In CHAMPION HFrEF population (prospective subgroup analysis), heart failure hospitalization rates were 28% lower than control (p = 0.0013) and mortality was 32% lower, trending toward significance (p = 0.06).
- Because there was such a strong signal for improved survival in the prospective study, a retrospective study was done on the CHAMPION HFrEF subgroup, splitting them into groups based on ability to tolerate GDMT.
  - **Group 1** (n = 455): tolerated at least one angiotensin-converting enzyme inhibitor (ACEI)/angiotensin receptor blocker (ARB) and/or beta blocker (BB)
  - **Group 2** (n = 337): tolerated both ACEI/ARB and BB

  - Heart failure hospitalization in Group 1 was 33% lower than control (p = 0.0002) (left panel, left points).
  - Heart failure hospitalization in Group 2 was 43% lower than control (p < 0.0002) (left panel, right points).
  - Mortality in Group 1 was 37% lower than control (p = 0.0293) (right panel, left points).
  - Mortality in Group 2 was 57% lower than control (p = 0.0052) (right panel, right points).

CONCLUSION

- PA pressure-guided heart failure management strategy resulted in significant reductions in hospitalizations and mortality in patients receiving prior optimal GDMT.
- Maximally tolerated GDMT at target doses is very important to control heart failure disease progression. There is apparent synergy between GDMT and hemodynamic monitoring in the control of heart failure disease progression.
- This retrospective analysis suggests the impact of GDMT on mortality and heart failure progression is significantly enhanced by avoiding decompensation events using guidance from the CardioMEMS™ HF System.
Retrospective Subanalyses

CARDIOMEMS™ HF SYSTEM-GUIDED PA PRESSURE MONITORING PROVIDED ACTIONABLE INFORMATION AND A MORE PERSONALIZED PHARMACOLOGICAL APPROACH, SO CLINICIANS COULD BETTER MANAGE HF

INTERVENTIONS LINKED TO DECREASED HEART FAILURE HOSPITALIZATIONS DURING AMBULATORY PULMONARY ARTERY PRESSURE MONITORING


- Medication changes based on PA pressure information were more effective in reducing heart failure hospitalizations than using signs and symptoms alone.

Figure 8. Frequency of Medication Changes by Drug Class

Figure 9.

*p < 0.05 PA Pressure Guided Heart Failure Management vs. SOC Heart failure Management.

No change represents where a medication was changed (e.g., dose frequency, route) that resulted in no net dose equivalent change.
**KEY TAKEAWAY:**

- At six months and for the full study duration (mean 15 months), remote PA pressure monitoring had a significant reduction in heart failure hospitalizations for patients with and without a history of MI in the treatment group vs. control (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>RRR at 6 Months for Treatment Group</th>
<th>RRR at 15 Months for Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of MI</td>
<td>30% (p &lt; 0.0039 vs. control)</td>
<td>46% (p &lt; 0.0001 vs. control)</td>
</tr>
<tr>
<td>No MI</td>
<td>25% (p = 0.016 vs. control)</td>
<td>23% (p = 0.021 vs. control)</td>
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**EFFECT OF CRT ON HEART FAILURE RELATED HOSPITALIZATIONS IN PATIENTS WITH REDUCED EF UTILIZING REMOTE PULMONARY ARTERY PRESSURES IN THE CHAMPION TRIAL**


- This subanalysis of the CHAMPION clinical trial evaluated the effect of PA pressure-guided therapy with the CardioMEMS™ HF System in patients with reduced ejection fraction (rEF < 40%; n = 430) with and without a cardiac resynchronization therapy (CRT) device.

- 40% (171 of 430) of rEF patients had CRT devices; of this cohort, 82 patients were in the treatment and 89 in the control group.

- 60% (259 of 430) of rEF patients did not have CRT devices; of this cohort, 126 patients were in the treatment group and 42 in the control group.

**KEY TAKEAWAYS:**

- Remote PA pressure data in the treatment group resulted in similar reductions in heart failure hospitalizations in patients with and without a history of MI in the treatment group vs. control.

- For patients in the rEF-CRT group, those who received PA pressure-guided therapy had significantly fewer heart failure hospitalizations (RRR = 24%; p = 0.0264).

- For patients in the rEF-no CRT group, PA pressure-guided therapy resulted in a RRR = 23%.

**THE UTILITY OF A WIRELESS IMPLANTABLE HEMODYNAMIC MONITORING SYSTEM IN PATIENTS REQUIRING MECHANICAL CIRCULATORY SUPPORT**

Feldman D, et al. *ASAIO.* 2018.27

- This subanalysis of the CHAMPION clinical trial evaluated the effect of PA pressure-guided therapy on optimizing medications, pump parameters and timing of ventricular assist device (VAD) intervention and transplantation in patients receiving a left ventricular assist device (LVAD) (n = 27).

**KEY TAKEAWAY:**

- LVAD patients who received PA pressure-guided therapy (15 out of 27 patients) had significantly shorter times to VAD intervention (p = 0.001), more changes to medical therapy based on hemodynamic information (p = 0.025) and shorter times between VAD intervention and heart transplantation (p = 0.001).

**THE UTILITY OF REMOTE WIRELESS PULMONARY ARTERY PRESSURE MONITORING IN PATIENTS WITH OR WITHOUT A HISTORY OF MYOCARDIAL INFARCTION: EXPERIENCE FROM THE CHAMPION TRIAL**


- This subanalysis of the CHAMPION clinical trial determined whether PA pressure monitoring affected the clinical outcomes of patients with and without a history of myocardial infarction (MI).

- 271 of the 550 NYHA Class III heart failure patients enrolled in the CHAMPION clinical trial had a history of MI and were randomized to either the control (n = 137) or treatment (n = 134) groups.

- At six months, there was a 2.2-day benefit of days alive outside the hospital for patients in the treatment group; at 15 months, this increased to 30.1 days.
TARGETING PULMONARY ARTERY PRESSURES IN THE TREATMENT OF CHRONIC HEART FAILURE: INSIGHTS FROM THE CHAMPION TRIAL


- This CHAMPION clinical trial subanalysis determined whether remote access to PA pressure data may provide a method to identify and treat high filling pressures in heart failure patients at increased risk for decompensation (n = 550).
- At implant, the mean PA pressure was similar in both control and treatment groups (31.8 ± 10.7 millimeters of mercury (mmHg) and 31.3 ± 11.1 mmHg, respectively).
- Average PA pressures increased during the six weeks prior to heart failure hospitalizations in both groups (p < 0.0001) and decreased significantly after successful in-hospital decongestion (p < 0.0001).
- Treatment patients with heart failure hospitalizations had lower pressures compared to control patients with heart failure hospitalizations at all time points prior to hospitalization.
  - Treatment patients also had lower PA pressures compared to the control patients regardless of hospitalization type (heart failure related or non-heart failure related).

KEY TAKEAWAYS:
- Higher PA pressures and increases in PA pressure were both associated with increased risk for heart failure hospitalizations.
- Heart failure treatment strategies that target both high PA pressure and increases in PA pressures may be effective strategies for lowering the risk of decompensation in chronic heart failure patients.

HEART FAILURE AND RESPIRATORY HOSPITALIZATIONS ARE REDUCED IN HEART FAILURE SUBJECTS WITH CHRONIC OBSTRUCTIVE PULMONARY DISEASE USING AN IMPLANTABLE PULMONARY ARTERY PRESSURE MONITORING DEVICE.


The purpose of this CHAMPION clinical trial subanalysis was to evaluate whether PA pressure-guided therapy reduced heart failure hospitalizations and respiratory event hospitalizations (REHs) in a cohort of patients with comorbid chronic obstructive pulmonary disease (n = 187).

KEY TAKEAWAYS:
- There was an overall reduction in PA pressures: patients in the treatment group (n = 91) had an average area under curve reduction of 202 mmHg days compared to the increase of 107 mmHg days in the control group (n = 96; p = 0.03). 
- At 15 months, there was a 41% reduction in heart failure hospitalization rates in the treatment group vs. the control group (0.55 vs. 0.96; HR 0.59; 95% CI 0.44 to 0.81; p = 0.0009).
- At 15 months, patients in the treatment group (n = 91) had a 62% reduction in REH (0.12 vs. 0.31; HR 0.38; 95% CI 0.21 to 0.71; p = 0.0023).

PULMONARY HYPERTENSION RELATED TO LEFT HEART DISEASE: INSIGHT FROM A WIRELESS IMPLANTABLE HEMODYNAMIC MONITOR

Benza, et al. JHLT. 2015.26

This CHAMPION clinical trial subanalysis evaluated the effect of PA pressure monitoring in heart failure patients with comorbid pulmonary hypertension (PH) (mean PA pressure > 25 mmHg).
- Data were obtained for 314 patients (59%) who had World Health Organization (WHO) Group II PH. Patients in the PH cohort were further stratified by transpulmonary gradient (TPG) and pulmonary vascular resistance.
- 67% (213 out of 314) of PH patients had a TPG ≤ 15.
- Patients without PH were at significantly lower risk for mortality than PH patients (HR 0.31; 95% CI 0.19 to 0.52; p < 0.0001).
- PH patients had higher heart failure hospitalization rates than non-PH patients (0.77/year vs. 0.37/year; HR 0.49; 95% CI 0.39 to 0.61; p < 0.001).
- In patients with and without PH, ongoing knowledge of hemodynamic data resulted in a reduction in heart failure hospitalization for PH patients (HR 0.64; 95% CI 0.51 to 0.81; p = 0.002) and for non-PH patients (HR 0.60; 95% CI 0.41 to 0.89; p = 0.01).
- Among PH patients, there was a reduction in the composite endpoint of death and heart failure hospitalization with ongoing knowledge of hemodynamics (HR 0.74; 95% CI 0.55 to 0.99; p = 0.04), but no difference in survival (HR 0.78; 95% CI 0.50 to 1.22; p = 0.28).

KEY TAKEAWAY:
- PH patients are at a high risk for adverse outcomes. Ongoing knowledge of hemodynamic variables may allow more effective treatment strategies to reduce morbidity of the disease.

LIMITATIONS OF RIGHT HEART CATHETERIZATION IN THE DIAGNOSIS AND RISK STRATIFICATION OF PATIENTS WITH PULMONARY HYPERTENSION RELATED TO LEFT HEART DISEASE: INSIGHT FROM A WIRELESS PULMONARY ARTERY PRESSURE MONITORING SYSTEM

Raina, et al. JHLT. 2015.25

- This CHAMPION sub-study compared the use of the CardioMEMSTM HF System with right heart catheterization (RHC) to diagnose and stratify risk in patients with PH.
- RHC identified 320 patients with PH (defined as mean PA pressure > 25 mmHg) and among these patients mean PA pressure obtained from RHC was similar to the CardioMEMS HF System's first-week PA pressure.
- RHC also identified 217 patients without PH (defined as mean PA pressure readings ≤ 25 mmHg) and 51% of them met this definition according to data obtained from the CardioMEMS HF System (18.5 for the RHC vs. 18.4 for the CardioMEMS HF System, p = 0.9208).
- The other 49% of patients identified by RHC as not having PH had first-week mean PA pressure readings > 25 mmHg with the CardioMEMS HF System, indicating PH.
Among the 217 patients using the CardioMEMS™ HF System diagnosed by RHC as non-PH, the 49% with first-week mean PA pressure reading > 25 mmHg had significantly higher heart failure hospitalization rates than the 51% of patients with readings ≤ 25 mmHg (0.49 vs. 0.25/year, p = < 0.0001).

**KEY TAKEAWAYS:**
- This analysis suggests that using RHC alone may result in PH underdiagnoses in patients with heart failure.
- In this study, the more frequent PA pressure monitoring with the CardioMEMS HF System provided better diagnostic and risk stratification compared with single RHC.

**IMPACT OF REMOTE, WIRELESS PULMONARY ARTERY HEMODYNAMIC MONITORING IN PATIENTS WITH ATRIAL FIBRILLATION AND CHRONIC HEART FAILURE: INSIGHTS FROM THE CHAMPION TRIAL**

Miller, et al. JACC. 2012.24

- This CHAMPION clinical trial subanalysis compared the baseline characteristics and impact of PA pressure-guided therapy on hospitalization rates in patients with a history of atrial fibrillation (AF) (n = 255) compared to those with normal sinus rhythm (n = 200).
- The AF cohort had significant baseline differences compared to the sinus rhythm cohort (older: 65 vs. 59; more often male):
  - 80% vs. 66%, more frequently had CRT or cardiac resynchronization therapy defibrillator (CRT-D) devices
  - 44% vs. 27%, higher mean PA pressures: 30.2 vs. 28.5 mmHg, etc.

**KEY TAKEAWAYS:**
- AF patients in the treatment group had a significantly lower heart failure hospitalization rate than those in the control group at six months (37%; p = 0.0004) and 15 months (41%; p < 0.0001).
- AF patients had a 57% higher heart failure hospitalization rate vs. non-AF patients (0.47 vs. 0.30 events/patient; p < 0.0001).

**BENEFITS OF PULMONARY ARTERY PRESSURE MONITORING IN PATIENTS WITH NYHA CLASS III HEART FAILURE AND CHRONIC KIDNEY DISEASE: RESULTS FROM THE CHAMPION TRIAL**


This subgroup data analysis from the CHAMPION clinical trial compared heart failure hospitalizations between NYHA Class III heart failure patients with chronic kidney disease (CKD) monitored (mean follow-up of 18 months) with PA pressure (n = 150) to those managed with SOC (n = 147).
- When CKD patients were managed with PA pressures, heart failure hospitalization rates were significantly reduced (42%) compared to patients with CKD managed according to SOC (0.48 vs. 0.83; HR 0.58; p < 0.001).
- Changes in CKD indicators (creatinine and glomerular filtration rates) were not adversely affected in the PA pressure monitored group.

**KEY TAKEAWAYS:**
- CKD in patients with heart failure is a frequent comorbidity that is associated with worse clinical outcomes, including higher heart failure hospitalization rates.
- For heart failure patients with CKD, PA pressure monitoring reduced heart failure hospitalizations by 42% compared to SOC heart failure management.
- Intensified heart failure medical therapy as a result of PA pressure monitoring was safe and did not adversely affect renal function.

**THERAPY GUIDED BY PA PRESSURE ALONE VS. SIGNS AND SYMPTOMS**

**PRESSURE FOR ACTION: IMPLANTABLE PULMONARY ARTERY PRESSURE SENSOR MEASUREMENTS ALONE BEAT CLINICAL SIGNS TO GUIDE PREVENTION OF HEART FAILURE HOSPITALIZATIONS**

Goldberg L, et al. HRS 2015 Abstract 36-02.29

- Data analysis from the CHAMPION clinical trial during the six-month primary endpoint period:
  - 550 Patients: 270 in the treatment group and 280 in the control group
- All interventions for patients in the PA pressure-managed group were characterized prospectively by investigators as triggered primarily by clinical findings OR by changes in PA pressure.
- Heart failure hospitalization rates were lowest in patients for whom all diuretic interventions were triggered by PA pressure (0.39 events/patient-year), despite this cohort having the highest baseline PA pressure (Figure 10).
- There was a statistically significant 67% relative risk reduction of heart failure hospitalizations if a patient’s diuretic interventions were managed with PA pressure alone vs. clinical signs only (HR 0.33; 95% CI 0.16 to 0.59; p = 0.0007).
- Medication changes based on PA pressure information were more effective in reducing heart failure hospitalizations than using signs and symptoms alone.

**Figure 10. Heart Failure Hospitalization Rate (Events/Year)**

Managing medical therapy based on PA pressures, along with follow-up lab and patient assessment led to significantly better outcomes than managing based on clinical signs and symptoms.
KEY TAKEAWAYS:

- Heart failure hospitalization rates (events/patient-year) were significantly reduced if a patient's diuretic management therapies were managed by:
  - PA pressure only compared to clinical signs (67% reduction).
  - PA pressure and clinical signs compared to clinical signs (46% reduction).
- Heart failure hospitalization rates were most effectively reduced by a management strategy based on PA pressures without reliance on clinical changes.
- This supports the strategy of early intervention prior to clinical signs to avert clinical decompensation and heart failure readmissions.1,2

CONCLUSION:

Managing medical therapy based on PA pressures, along with follow-up lab and patient assessments, led to significantly better outcomes than managing based on clinical signs and symptoms.

MEDICARE-ELIGIBLE POPULATIONS

PULMONARY ARTERY PRESSURE–GUIDED HEART FAILURE MANAGEMENT REDUCES 30-DAY READMISSIONS


- This data analysis from the CHAMPION clinical trial evaluated 30-day readmissions and heart failure hospitalizations between patients monitored with the CardioMEMS™ HF System, and those whose was not monitored over a period of 18 months.
- 245 patients were included in the analysis; 120 in the PA pressure treatment group and 125 in the SOC control group.
- In this analysis, patients managed with PA pressure compared to those managed according to SOC experienced:
  - 58% reduction in all-cause 30-day readmissions (0.07 vs. 0.18; HR 0.42; p = 0.0062)*
  - 78% reduction in heart failure 30-day readmissions (0.02 eppy vs. 0.10 eppy; HR 0.22; p = 0.0027)*
  - 49% reduction in heart failure hospitalizations (0.34 eppy vs. 0.67 eppy; HR 0.51; p < 0.0001)*

*Event rates are based on events/patient-year.

KEY TAKEAWAYS:

- This retrospective analysis of the CHAMPION clinical trial demonstrated that PA pressure-guided management of Medicare-eligible heart failure patients significantly reduced 30-day readmissions, which may help to alleviate the economic burden associated with heart failure readmissions.
- This analysis supports results from the CHAMPION clinical trial results demonstrating a 37% reduction in heart failure hospitalizations and improved quality of life with PA pressure-guided heart failure management in NYHA Class III heart failure patients irrespective of Medicare eligibility.1

Figure 11. Subgroup Analysis: Medicare-eligible population shows significant reduction in 30-day readmissions

<table>
<thead>
<tr>
<th>Events/Patient-year</th>
<th>Control (Standard of Care)</th>
<th>Treatment (PA Pressure Monitor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Failure</td>
<td>117</td>
<td>60</td>
</tr>
<tr>
<td>p &lt; 0.0001</td>
<td>49% reduction</td>
<td></td>
</tr>
<tr>
<td>Heart Failure</td>
<td>31</td>
<td>13</td>
</tr>
<tr>
<td>p = 0.0062</td>
<td>58% reduction</td>
<td></td>
</tr>
<tr>
<td>All-Cause</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>p &lt; 0.0027</td>
<td>78% reduction</td>
<td></td>
</tr>
<tr>
<td>Heart Failure</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Statistically significant reductions in 30-day readmission and heart failure hospitalization in Medicare-eligible patients 65 years or older (n = 245), when PA pressures are monitored using the CardioMEMS™ HF System.

HEART FAILURE PATIENTS WITH COMMON COMORBIDITIES

PA Pressure-guided Therapy Has Been Shown to Consistently Reduce Heart Failure Hospitalizations in Patients with Common Heart Failure Comorbidities

Heart failure is often associated with a variety of comorbidities such as respiratory disease, coronary artery disease and AF. These comorbidities contribute to disease progression and may alter the response to treatment. This section highlights additional subgroup analyses from the CHAMPION clinical trial that consistently show that PA pressure-guided therapy reduces heart failure hospitalizations in patients with common heart failure comorbidities. Table 2 summarizes the rate of heart failure hospitalizations across the different studies.

The CHAMPION Trial Subgroup Analyses: Reduction of HF Hospitalization in Patient Groups with Common Comorbidities

Table 2. Patients with common heart failure comorbidities have consistent reduction in heart failure hospitalizations with PA pressure-guided therapy.

<table>
<thead>
<tr>
<th>Sub-group or Comorbidity</th>
<th>n (control)</th>
<th>n (treatment)</th>
<th>Follow-up Period (months)</th>
<th>Reduction of Heart Failure Hospitalization Rate in Treatment Group vs. control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medicare population</td>
<td>125</td>
<td>120</td>
<td>18</td>
<td>49%, p &lt; 0.0001</td>
</tr>
<tr>
<td>HFrEF</td>
<td>56</td>
<td>59</td>
<td>18</td>
<td>50%, p &lt; 0.0001</td>
</tr>
<tr>
<td>HFrEF following GDMT</td>
<td>174</td>
<td>163</td>
<td>17</td>
<td>43%, p &lt; 0.0001</td>
</tr>
<tr>
<td>CRT-D or ICD following GDMT</td>
<td>146</td>
<td>129</td>
<td>18</td>
<td>43%, p &lt; 0.0001</td>
</tr>
<tr>
<td>History of myocardial infarction</td>
<td>137</td>
<td>134</td>
<td>15</td>
<td>46%, p &lt; 0.001</td>
</tr>
<tr>
<td>COPD</td>
<td>96</td>
<td>91</td>
<td>15</td>
<td>41%, p = 0.0009</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>163</td>
<td>151</td>
<td>15</td>
<td>36%, p = 0.0002</td>
</tr>
<tr>
<td>AF</td>
<td>135</td>
<td>120</td>
<td>15</td>
<td>41%, p &lt; 0.0001</td>
</tr>
<tr>
<td>Chronic kidney disease</td>
<td>150</td>
<td>147</td>
<td>15</td>
<td>42%, p = 0.0001</td>
</tr>
</tbody>
</table>

Patients with common heart failure comorbidities and patients in important subgroups have consistent reduction in heart failure hospitalizations with PA pressure-guided therapy.

ALSO, SEE GIVERTZ, ET AL, ABOVE, IN RETROSPECTIVE SUBGROUP ANALYSES:

PULMONARY ARTERY PRESSURE–GUIDED MANAGEMENT OF PATIENTS WITH HEART FAILURE AND REDUCED EJECTION FRACTION.


The CardioMEMS™ HF System Commercial Experience: Results from Real-world Studies

IMPACT OF PRACTICE-BASED MANAGEMENT OF PA Pressures in 2000 Patients Implanted with the CardioMEMS Sensor.


Observational Study from the First 2000 Commercially Implanted Patients from the Merlin.net™ Patient Care Network Database

Post-approval Observational Study of the CardioMEMS™ HF System

Large (N = 2000) observational study from first 2000 commercially implanted patients

Figure 12. Transmissions Compliance

Patients consistently upload pressures:
Median 1.2 days between transmissions

Providers consistently treat pressures:
Larger treatment effect in the real-world than CHAMPION
PATIENTS’ PRESSURE REDUCTION STRATIFIED BY EJECTION FRACTION AND BY GENDER

Pressures Are Reduced Equally Well in HFrEF and HFpEF, as well as Male and Female

Figure 13. AUC Mean PA pressure Stratified by Ejection Fraction

Figure 14. AUC Mean PA pressure Stratified by Gender

Figure 15. CHAMPION Control Cohort

Figure 16. CHAMPION Treatment Cohort

Figure 17. General-use Cohort


Pressure Changes Stratified by Baseline PA Pressure


KEY TAKEAWAYS FROM HEYWOOD, ET AL:

- High transmission compliance
- Data drove appropriate patient care
- Same results in HFpEF and HFrEF
- “Long-term patient acceptance and adherence is clearly demonstrated.”
- “The magnitude of pressure lowering ... was significantly larger than was seen in the pivotal clinical trial.”
AMBULATORY HEMODYNAMIC MONITORING REDUCES HEART FAILURE HOSPITALIZATIONS IN “REAL-WORLD” CLINICAL PRACTICE

Desai AS, et al. JACC. 2017.31

Real-world Use of the CardioMEMSTM HF System: Reduced heart failure hospitalization and associated costs in a large retrospective cohort (n = 1114) from a Medicare Claims database — six and 12 months of follow-up

Figure 18. Cumulative Heart Failure Hospitalization during Period Before and After CardioMEMSTM HF System Implant

45% reduction at 6 months
p < 0.001

HEMODYNAMIC-GUIDED HEART-Failure Management Using a Wireless Implantable Sensor: Infrastructure, Methods, and Results in a Community Heart Failure Disease-Management Program.


KEY TAKEAWAY:

• Hemodynamic-guided heart failure management leads to significant improvements in NYHA class and heart failure hospitalization rate in a small single-center study in a real-world setting, compared with usual care delivered in a comprehensive disease-management program.
  – Three-fold greater improvement in Kansas City Cardiomyopathy Questionnaire scores
  – Increase in 6MW distance: Average increase of 96 meters at 90 days vs. no increase in the SOC group

LOWER MORTALITY AND HEART FAILURE HOSPITALIZATION FOLLOWING IMPLANT OF AN AMBULATORY HEMODYNAMIC SENSOR


This study examined the impact of ambulatory hemodynamic monitoring with CardioMEMS HF System on rates of mortality and heart failure hospitalization in clinical practice using data from the 100% Medicare claims dataset.

STUDY OBJECTIVES

• Retrospective study, large cohort (n = 2174), using novel matching procedure from 100% Medicare claims database
• Studied outcomes in similar treatment and control cohorts

KEY TAKEAWAYS FROM DESAI:

• Real-world reduction in heart failure hospitalization after CardioMEMSTM HF System Implant
  – 45% reduction at six months
• Significant cost reductions for hospitalization
  – $10,510 per patient — six months
  – $13,190 per patient — year
These benefits support the real-world effectiveness of this approach to heart failure management
HEALTH ECONOMIC IMPACT OF A PULMONARY ARTERY PRESSURE SENSOR FOR HEART FAILURE TELEMONITORING: A DYNAMIC SIMULATION.
SUMMARY:
This simulation estimated the reductions of heart failure hospitalizations with PA guided care, the improvement on quality of life and the economic savings as a result of implementation in the German healthcare system. This simulation also showed the rise of heart failure prevalence numbers in the context of an aging population, and given the considerable burden of heart failure, the potential of a PA pressure monitoring system to improve the management of heart failure patients and enable cost savings at the same time is substantial.

COST EFFECTIVENESS ASSESSMENT OF PULMONARY ARTERY PRESSURE MONITORING FOR HEART FAILURE MANAGEMENT (AB36-01)
• This economic analysis to determine the cost-effectiveness of PA pressure monitoring was based on CHAMPION clinical trial data.
• A Markov cohort simulation model was used to approximate the course of management observed in the CHAMPION clinical trial for the treatment (PA pressure management) and control (SOC) groups.
• CHAMPION clinical trial data was used to estimate the event rates, mortality and quality of life.
• The base case follow-up period was five years, and costs related to all-cause comprehensive management were used.
• In this economic analysis, PA pressure-guided management of the CardioMEMS™ HF System indicated patients showed:
  – Incremental cost-effectiveness ratio (ICER) of $30,167 comparing comprehensive management over a five-year time horizon.

KEY TAKEAWAYS:
• This economic analysis showed an ICER of $30,167 per quality-adjusted life year (QALY) based on all-cause comprehensive management of heart failure patients modeled over a five-year time horizon.
• The ICER of $30,167 is below the U.S. accepted ICER threshold of $50,000 per QALY and well under the WHO threshold of approximately $160,000 for the U.S. (based on GDP).18,19
• Cost-effectiveness is attributable to a reduction in heart failure hospitalization rates.

KEY TAKEAWAY FROM THE ABRAHAM PRESENTATION:
• Observed 30% reduction in mortality at 12 months following implant ... and a 24% reduction in heart failure hospitalization
  – Supports the hypotheses being evaluated in the GUIDE-HF investigational device exemption (IDE) study.
COST-EFFECTIVENESS OF REMOTE CARDIAC MONITORING WITH THE CARDIOMEMS HEART FAILURE SYSTEM


KEY RESULTS:
Mortality trends lower for CardioMEMSTM HF System vs. SOC:
• Based on the model’s base case, half (50.4%) of the original CardioMEMS HF System patients were dead at 60 months vs. 50% mortality at 40 months for patients on SOC.
• At the end of the 60 months, 49.6% of CardioMEMS HF System patients remained alive vs. 23.8% of SOC patients.
Cost/QALY was in the high-value space:
• Device cost/QALY was well below $50,000, remaining in the high-value space (based on American College of Cardiology (ACC) and American Heart Association guidelines).

CONCLUSION:
• The CardioMEMS HF System was found to be cost-effective, with an ICER of $44,832 per QALY.
• This places the CardioMEMS HF System in the high-value category compared to LVADs ($128K–$209K/QALY) and CRT-D ($62K/QALY).
• “For heart failure patients meeting current indications, the CardioMEMS HF System may represent an important clinical advance, while at the same time being a cost-effective treatment for heart failure.”

Table 3. Model Results: Base Case

<table>
<thead>
<tr>
<th>Five-year costs and outcomes</th>
<th>CardioMEMSTM</th>
<th>Standard of Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs</td>
<td>$188,880</td>
<td>$162,772</td>
</tr>
<tr>
<td>Implant: device, procedure, complications</td>
<td>$19,111</td>
<td>$0</td>
</tr>
<tr>
<td>Inpatient costs</td>
<td>$108,124</td>
<td>$113,199</td>
</tr>
<tr>
<td>Outpatient costs (including monitoring)</td>
<td>$61,645</td>
<td>$49,573</td>
</tr>
<tr>
<td>Total accumulated QALYs</td>
<td>2.509</td>
<td>1.926</td>
</tr>
<tr>
<td>Incremental cost-effectiveness ratio (cost per QALY gained)</td>
<td>$44,832</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Base Case Input Parameters: Costs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cost (USD)1</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CardioMEMs device (per device)</td>
<td>$17,750</td>
<td>Average sales price</td>
</tr>
<tr>
<td>Implantation procedure</td>
<td>$1,280</td>
<td>Medicare: $1,138; CPT 93451, 93568, 33210, 2016 MFS; Commercial: $1,707 (MFS × 1.5)</td>
</tr>
<tr>
<td>Complications, each</td>
<td>$5,770</td>
<td>Martinson et al inflate to 2016</td>
</tr>
<tr>
<td>Hospitalizations</td>
<td></td>
<td>Takes into account % Medicare vs. commercial</td>
</tr>
<tr>
<td>Heart failure hospitalization</td>
<td>$21,007</td>
<td>Martinson et al inflate to 2016</td>
</tr>
<tr>
<td>Non-heart failure hospitalization</td>
<td>$24,367</td>
<td>Martinson et al inflate to 2016</td>
</tr>
<tr>
<td>Monthly monitoring</td>
<td>$47</td>
<td>Martinson et al inflate to 2016</td>
</tr>
<tr>
<td>Outpatient costs, routine care (per year)</td>
<td>$19,576</td>
<td>Martinson et al inflate to 2016</td>
</tr>
</tbody>
</table>

1. Costs are presented in 2016 dollars and were inflated or discounted as described in the Methods. All costs are weighted based on the assumption that 75% of patients are covered by Medicare and 25% have commercial coverage.
PULMONARY ARTERY PRESSURE-GUIDED HEART FAILURE MANAGEMENT: US COST-EFFECTIVENESS ANALYSES USING THE RESULTS OF THE CHAMPION CLINICAL TRIAL.


KEY RESULTS:

The primary effectiveness endpoint was the ICER comparing the costs and QALYs of heart failure hospitalization outcomes in the CHAMPION treatment and control groups. The model was used to extrapolate this endpoint to five years.

Over the five-year projections, patients in the treatment group had average QALYs of 2.56 with a total cost of $140,966; patients in the control group had QALYs of 2.16 with a total cost of $133,681. The ICER was $18,515 per QALY (Table 5).

Table 5. Cost-effectiveness analysis base-case and survival over a five-year time horizon

<table>
<thead>
<tr>
<th></th>
<th>Primary CEA endpoint: heart failure hospitalization outcomes</th>
<th>All-cause hospitalization outcomes</th>
<th>Comprehensive patient management outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment group</td>
<td>Control group</td>
<td>Treatment group</td>
</tr>
<tr>
<td>Cumulative QALYs</td>
<td>2.56</td>
<td>2.16</td>
<td>2.56</td>
</tr>
<tr>
<td>Cumulative average years of survival</td>
<td>3.70</td>
<td>3.47</td>
<td>3.70</td>
</tr>
<tr>
<td>Incremental cost-effectiveness ratio (U.S. $/QALY)</td>
<td>U.S. $12,262</td>
<td>U.S. $18,515</td>
<td>U.S. $29,592</td>
</tr>
<tr>
<td>Cost reduction for each patient under treatment post implant (U.S. $/year)</td>
<td>U.S. $4,443</td>
<td>U.S. $5,261</td>
<td>U.S. $5,296</td>
</tr>
</tbody>
</table>

1. Costs saving per life year for the treatment group.

CONCLUSION:

This study, based on the results of the CHAMPION clinical trial, used standard economic modelling to show that PA pressure-guided management of heart failure using the CardioMEMS™ HF System is cost-effective from the perspective of U.S. payers. The ICERs, when considered for heart failure management or comprehensive management, were well below the conventional U.S. acceptability threshold of $50,000.
Post-approval Study

REDUCTION OF HF HOSPITALIZATION IN THE CARDIOMEMS™ HF SYSTEM POST-APPROVAL STUDY

Raval, et al. Presented at HFSA 2017.35

Figure 21.

In the post-approval study, there were 56 heart failure hospitalizations (0.20 events/pt-6m) in 43 pts

MEDICATION CHANGES SIGNIFICANTLY REDUCED IN FIRST 90 DAYS VS. SECOND 90 DAYS IN THE PAS

Figure 22. Medication Changes — First 90 days vs. Second 90 days

65% of the overall heart failure medication changes were made in the first 90 days, with trends of stabilization and significantly fewer medication changes during the second 90 days.
Significantly greater reductions in mean PA pressure for the PAS cohort relative to the CHAMPION control group after six months, and qualitatively greater reductions compared to the CHAMPION treatment group.

GUIDE-HF

The Hemodynamic GUIDE Monitoring in HF (GUIDE-HF) IDE trial will include a Randomized Arm and a Single Arm, with the following objectives:

- **GUIDE-HF Randomized Arm**: The objective of the GUIDE-HF Randomized Arm is to determine if PA pressure-guided heart failure management using the CardioMEMSTM HF System improves health outcomes in NYHA Class II–IV heart failure patients with either elevated NT-proBNP (or BNP) or a prior heart failure hospitalization. Enrollment target: n = 1,000

- **GUIDE-HF Single Arm**: The objective of the GUIDE-HF Single Arm is to demonstrate the equivalence of the effect of PA pressure-guided heart failure management on health outcomes between NYHA Class III heart failure patients with elevated NT-proBNP (or BNP) only and those with a prior heart failure hospitalization only. Enrollment target: n = 2,600

CLINICAL RESEARCH PAPERS BY TOPIC

**IMPROVED QUALITY OF LIFE AND FUNCTIONAL CAPACITY**


**DECREASED HEART FAILURE HOSPITAL ADMISSIONS AND READMISSIONS**


**DECREASED PA PRESSURES**


**OPTIMIZED MANAGEMENT IN HFP EF**

THE CARDIOMEMS™ HF SYSTEM IS PROACTIVE AND ACTIONABLE; GDMT IS REACTIVE AND INEXACT


REHOSPITALIZATION = INCREASED MORTALITY


REDUCED MORTALITY


PATIENT SELECTION AND WORKFLOW

- Adamson White Paper (on Map).

- Lisa Rathman, Lancaster General: HFSA Abstract — Holding up both Ends of the Bargain: Ambulatory Hemodynamic Monitoring using CardioMEMS.

REIMBURSEMENT/HEALTHCARE ECONOMICS/REDUCED HOSPITALIZATION COSTS


