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The emerging role of non-invasive cardiac and pulmonary pressure sensing in inpatient cardiology and hospitalized heart failure workflow

DRAFT VERSION

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Disclaimer. This white paper is a scientific and conceptual overview of emerging approaches to non-invasive hemodynamic monitoring. It does not describe any specific approved medical device, does not constitute marketing material or labeling, and should not be interpreted as instructions for use or as evidence of regulatory clearance or approval.

Executive summary

...most patients still had signs of congestion seven days after hospitalization, and residual congestion was independently associated with higher rates of rehospitalization and death.

Heart failure teams repeatedly face the same hemodynamic blind spots at the bedside. In the emergency department, clinicians must decide who truly requires admission versus who might be safely managed in observation or hospital-at-home settings, often without reliable insight into filling pressures. On the ward, teams must judge when a patient is genuinely decongested and ready for discharge, despite the well-described problem of residual congestion. After discharge, they are asked to rapidly up-titrate guideline-directed medical therapy (GDMT) while lacking repeatable information on how close a patient is to hemodynamic decompensation. This white paper explores how non-invasive pressure assessment could support these decisions by adding a missing, objective hemodynamic layer to existing clinical, imaging, and biomarker-based workflows.

Heart failure (HF) is a leading cause of hospitalization and readmission worldwide, with substantial clinical and economic burden for healthcare systems. Hospitalizations account for the largest share of direct HF costs, and many patients are readmitted within 30–90 days of discharge.[1,2] In this context, there are two discrete areas of need: 1) Emergency department disposition & inpatient management, & 2) post-discharge monitoring. More than 80% of patients presenting to the emergency department (ED) with acute heart failure are admitted to the hospital, even though only a minority have life-threatening conditions requiring intensive care such as cardiogenic shock, acute coronary syndrome, or respiratory failure. [37,38] For patients who are hospitalized, the primary driver of admissions for acute decompensated heart failure (ADHF) patients is congestion (elevated intracardiac and pulmonary pressures)[1,3,4]. The primary therapeutic goals are relief of congestion and optimization of guideline-directed medical therapy (GDMT). Today's inpatient heart failure workflow relies heavily on subjective assessment and surrogate markers of pressure and volume. Direct hemodynamic data, although highly actionable, is rarely used because of the invasive, costly, and operationally impractical application for routine monitoring. The weeks immediately following hospital discharge represent the highest-risk period for patients with HF driven by multiple factors: incomplete decongestion at discharge, inadequate GDMT dosing, poor treatment adherence, delayed follow-up, and difficulty detecting early re-accumulation of congestion before symptoms become severe enough to trigger an ED visit. While we have only recently begun to see the introduction of implantable systems to monitor patients in a post-discharge setting, there remains a significant need for less invasive cost-effective pressure monitoring devices across sites of care. The most immediate need is in the inpatient care setting.

Up to
36%
reduction in LOS

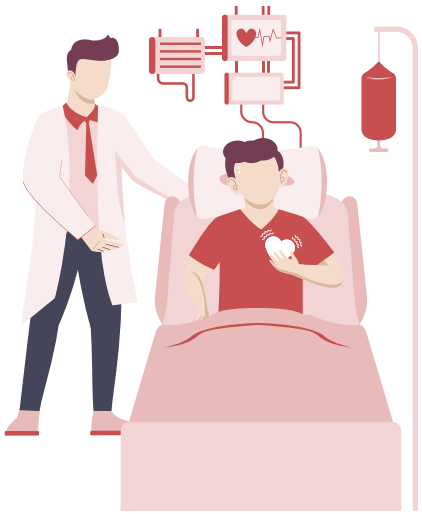
Over the past decade, several studies have shown that hemodynamic- and congestion-guided care can improve outcomes. Implantable pulmonary artery (PA) pressure sensors have demonstrated that using pressure trends to guide therapy can significantly reduce HF hospitalizations and improve quality of life.[5–8] Non-invasive lung-fluid monitoring has shown that adding an objective congestion metric to discharge decisions and early follow-up can reduce short-term adverse events in recently hospitalized patients.[4,9] Contemporary heart failure guidelines simultaneously emphasize early achievement of euvolemia and rapid initiation and up-titration of guideline-directed medical therapy (GDMT) during and shortly after hospitalization.[1,10]

At the same time, recent work has highlighted the limitations of existing non-invasive surrogates. A recent large analysis using non-invasive vitals and routine clinical variables with machine learning showed only weak correlation with actual intracardiac pressures and poor discrimination of clinically meaningful thresholds.[11] These and other negative or neutral findings underscore both the centrality of hemodynamics and the need for more direct, repeatable, and scalable non-invasive approaches.

This white paper aims to provide an overview of:

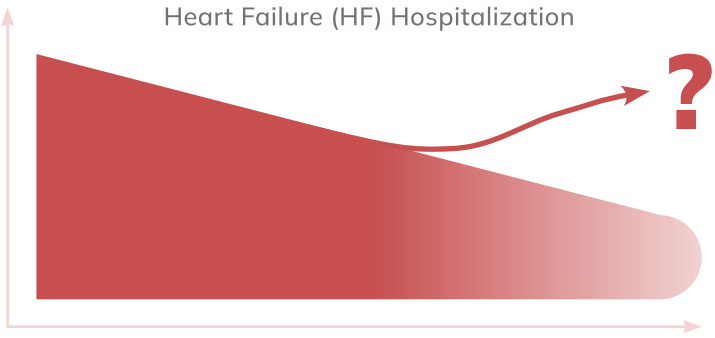
1. the burden of HF and the role of residual congestion across emergency department (ED), inpatient, and post-discharge care
2. current guideline recommendations and evidence for hemodynamic-guided care and GDMT optimization in hospitalized HF patients
3. the current utilization of invasive and non-invasive volume and pressure monitoring devices in HF care
4. the performance and limitations of existing non-invasive volume and pressure surrogates
5. design principles and emerging approaches for next-generation non-invasive cardiac and pulmonary pressure sensing
6. potential applications of non-invasive hemodynamics for in-hospital and early post-discharge GDMT optimization
7. the economic and workflow implications of improved hemodynamic assessment tools
8. the future outlook for integrating non-invasive pressure sensing into routine HF care

1 The burden of heart failure hospitalization and residual congestion



...most patients still had signs of congestion seven days after hospitalization, and residual congestion was independently associated with higher rates of rehospitalization and death.

Patients with heart failure (HF) frequently present to the emergency department (ED) with acute or worsening congestion, and HF remains one of the leading causes of unplanned hospitalization and readmission in adults.[1,2,25–27] Within 30–90 days of discharge, a substantial proportion of patients are rehospitalized, often with persistent or recurrent congestion as a key driver of adverse outcomes.[2,3,10,19,21] These patterns highlight that the burden of HF is not confined to the index admission but spans the ED presentation, the inpatient stay, and the high-risk early post-discharge period.



40% Are undertreated at discharge

↓

25% are readmitted within 30 days

Tracking weight, urine output, echo parameters & swelling of veins on the neck, lag behind true physiology and are subjective, and have failed to show positive outcomes in trials

Figure 1. Residual congestion in the hospitalized heart failure patient workflow is an important contributor to readmission rates

Heart failure affects tens of millions of individuals worldwide, with prevalence and incidence increasing in many regions.[2,6,12,13] HF is among the most common causes of hospitalization in adults and a major driver of healthcare expenditure.[1,2,6,19] A recent systematic review of the economic burden of HF hospitalizations in the United States reported mean HF-specific inpatient costs ranging from approximately $10,700 to $17,800 per admission, with HF hospitalizations accounting for roughly half or more of direct HF-related medical costs.[2]

Congestion, or elevated cardiac filling pressures and fluid accumulation, is the main reason for ADHF admission.[3,8,20,21] Multiple observational studies have shown that residual congestion at discharge is common and strongly associated with worse outcomes. In the large cohort described by Rubio-Gracia et al., most patients still had signs of congestion seven days after hospitalization, and residual congestion was independently associated with higher rates of rehospitalization and death.[3,21] Similar findings have been reported when residual pulmonary congestion is assessed by lung ultrasound B-lines, impedance-derived indices, or composite congestion scores.[5,10,12,16,18,22]

Despite this, congestion assessment in routine care remains challenging. Traditional tools—such as symptoms and signs, weight, natriuretic peptides, chest imaging, and echocardiography—provide important information but are limited in their ability to reliably and repeatedly track filling pressures (see Section 4 for a detailed overview).

Right heart catheterization remains the gold standard for measuring right atrial pressure (RAP), PCWP, and pulmonary artery pressures. [1] However, its invasive nature, requirement for specialized staff and facilities, and procedural risks limit its use to selected patients and specific decision points. As a result, most hospitalized HF patients are managed based on indirect and sometimes conflicting markers of congestion rather than on direct hemodynamic measurements.[1,20,24a]

2 ED and inpatient hemodynamics, guidelines, and GDMT in hospitalized heart failure patients

Clinicians may hesitate to initiate or up-titrate GDMT if they are uncertain about the patient's true hemodynamic reserve.

In the emergency department and inpatient ward, clinicians must rapidly classify hemodynamic status, relieve congestion, and initiate or optimize guideline-directed medical therapy (GDMT) for patients hospitalized with HF.[1,10,20] Contemporary guidelines and trials emphasize assessment of congestion from ED triage through discharge, with a goal of achieving hemodynamic and clinical euvolemia while safely implementing or up-titrating GDMT.[1,3,10,15,20] Yet, in routine practice, most day-to-day decisions across this pathway still rely on indirect surrogates such as symptoms, physical examination, natriuretic peptides, and imaging, rather than on direct measures of cardiac filling pressures.[1,3,10,15,20]

In parallel, guidelines and recent trials have shifted toward more aggressive initiation and up-titration of GDMT during and immediately after hospitalization. Foundational therapy for HF with reduced ejection fraction (HFrEF) now includes evidence-based beta-blockers, renin–angiotensin system blockers (preferably an angiotensin receptor–neprilysin inhibitor), mineralocorticoid receptor antagonists, and sodium–glucose co-transporter 2 inhibitors, often complemented by diuretics, device therapy, and other agents as appropriate.[1] For HF with mildly reduced and preserved EF (HFmrEF and HFpEF), SGLT2 inhibitors and aggressive management of comorbidities are recommended.[1] Guideline documents increasingly advocate initiation of multiple GDMT classes before discharge, provided patients are hemodynamically stable and decongestion is progressing.[1,10]

The STRONG-HF trial provides robust randomized evidence supporting this strategy.[10,14] Patients hospitalized for acute HF were randomized near discharge to usual care or to a high-intensity strategy involving rapid up-titration of GDMT (targeting near-maximal doses within weeks) and close follow-up with NT-proBNP-guided adjustments. The high-intensity group experienced a significant reduction in the composite of all-cause death or HF readmission at 180 days, alongside improved symptoms and quality of life.[10,14] These findings reinforce the concept that the peri-hospitalization window is a critical opportunity to establish and optimize disease-modifying therapy.

However, implementing such strategies in real-world practice can be challenging. Clinicians may hesitate to initiate or up-titrate GDMT if they are uncertain about the patient's true hemodynamic reserve. For example, a patient who appears clinically euvolemic but retains elevated PCWP and RAP may be at higher risk of hypotension or renal dysfunction if vasodilators or neurohormonal antagonists are pushed aggressively. Conversely, a patient who appears still mildly congested by symptoms and signs but whose filling pressures have normalized may be ready for more intensive GDMT, and continued escalation of diuretics could be counterproductive.[1,3,10,21] More precise, preferably non-invasive hemodynamic assessment could therefore support both decongestion decisions and GDMT optimization.

2.1 Many patients could be managed safely outside the hospital

Emergency department (ED) disposition is a major driver of heart failure (HF) bed-days. More than 80% of patients presenting to the ED with acute heart failure (AHF) are admitted, even though only a minority have life-threatening conditions such as cardiogenic shock, ongoing myocardial ischemia, or respiratory failure requiring intensive care.[27,28] Contemporary analyses suggest that up to half of current AHF admissions may be potentially avoidable, provided that low-risk patients can be reliably identified and supported in structured outpatient or home-based programs.[27–29]

ED consensus documents and risk-stratification studies consistently highlight that a substantial subset of AHF patients present with isolated congestion, are hemodynamically stable, and do not require invasive procedures or prolonged monitoring; for these patients, the main therapeutic need is timely intravenous diuresis, short-term observation, and close follow-up rather than traditional multi-day hospitalization.[28,29] However, decisions are currently made with limited objective hemodynamic data, and existing biomarkers and risk scores have had only modest impact on admission patterns.[23,29]

Randomized trials, meta-analyses, and recent hybrid 'hospital-at-home' pilots suggest that, in carefully selected HF patients, home- or virtual-ward care can achieve outcomes comparable to inpatient treatment while reducing bed utilization.[30–34]

Hemodynamically stable, lower-risk patients with worsening congestion might be treated in "hospital at home" or virtual-ward pathways rather than be admitted, provided that robust risk assessment, reliable

These negative and neutral findings underscore both the centrality of hemodynamics and the need for more direct, repeatable, and scalable non-invasive approaches.

Bedside measurements must be obtainable… within minutes, with clear guidance on sensor placement and automated quality checks…suitable for serial measurements (e.g., daily or more often in unstable patients).

congestion metrics, and close multidisciplinary follow-up are in place. Objective non-invasive hemodynamic assessments will be a key enabler of such models by helping ED and HF teams distinguish patients who truly require in-hospital monitoring from those who can safely receive hospital-level care in the home environment.

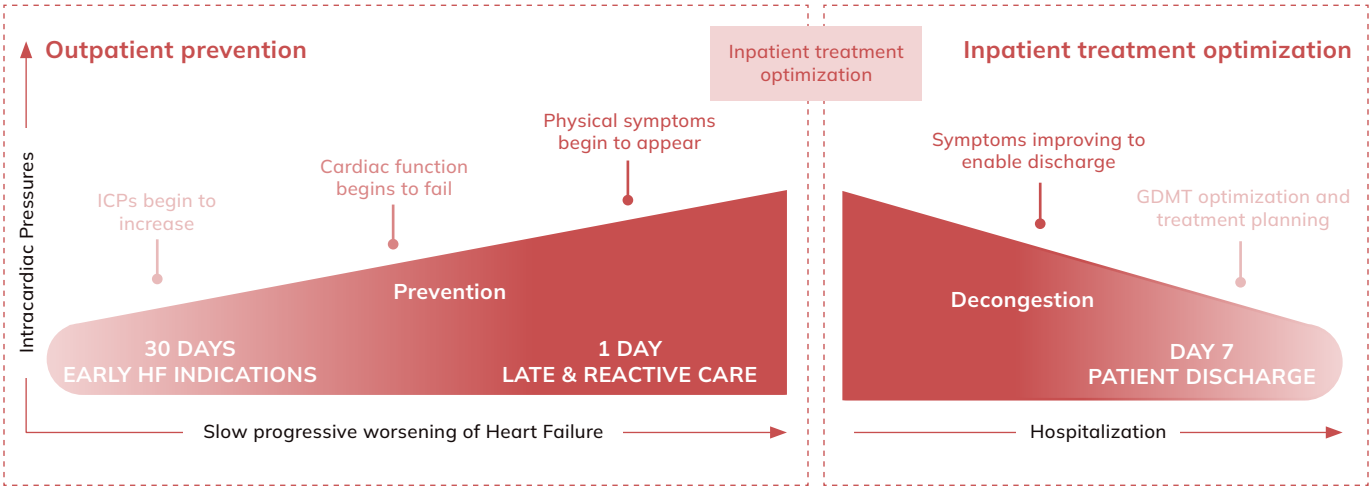


Figure 2. Successful heart failure patient management requires an end-to-end approach, enabling early detection & preventive care in the outpatient setting, coupled with improved inpatient decongestion and treatment optimization

3 Current utilization of invasive and non-invasive volume and pressure monitoring

For patients presenting with or living with heart failure (HF), direct hemodynamic assessment is currently concentrated in relatively narrow segments of care. Right heart catheterization (RHC) remains the reference standard for measuring intracardiac and pulmonary artery pressures and for characterizing hemodynamic profiles.[1,20,24] Contemporary guidelines and expert consensus documents highlight its value in advanced or refractory HF, cardiogenic shock, or when symptoms and non-invasive findings are discordant, rather than as a routine monitoring tool for all patients.[1,20] However, the need for invasive vascular access, specialized staff, catheterization-laboratory resources, and the associated procedural risks and costs mean that RHC is generally used at a few critical decision points, not as a modality for serial tracking of congestion across the emergency department (ED), ward, and post-discharge continuum.[1,2,19,20]

Consequently, ED disposition decisions and most inpatient management pathways still rely on indirect surrogates of congestion—symptoms and physical examination findings, natriuretic peptides, chest radiography, lung ultrasound, echocardiography, body weight, and urine output—rather than on objective, serial measures of intracardiac or pulmonary pressures.[1–3,10,15,19–21] Although these tools are valuable and widely available, they do not provide the type of continuous or near-real-time hemodynamic information that invasive monitoring can offer, and they may fail to detect worsening congestion until decompensation is clinically apparent.[2,3,10,19,21]

Outside of the catheterization laboratory, implantable pulmonary artery (PA) pressure sensors provide a means to obtain frequent or daily hemodynamic data in selected ambulatory patients with chronic HF. Randomized and long-term follow-up studies of wireless PA pressure monitoring have demonstrated that pressure-guided management can significantly reduce HF hospitalizations compared with standard care based on symptoms and conventional surrogates, and is associated with more frequent therapy adjustments and improvements in quality of life.[5–7,13] These systems are typically reserved for higher-risk populations, often with prior decompensation, and are implemented in specialized programmes that can support device implantation, remote data review, and protocolized therapy adjustments.[5–7,13,19]

Up to
50%
of HF admissions potentially avoidable

In parallel, several non-invasive technologies have been developed to estimate thoracic fluid content or lung congestion as a proxy for volume status. Remote dielectric sensing systems, for example, use low-power electromagnetic signals across the chest to quantify lung fluid percentage within seconds and have shown feasibility for identifying congestion in outpatients and in patients presenting with acute decompensated HF.[4,9] Such systems have been integrated into remote monitoring programs or used at the point of care to augment symptoms, weight, natriuretic peptides, and imaging, and they illustrate how repeated, non-invasive measurements can detect changes in congestion that precede overt clinical deterioration.[4,9,15,16,18]

Despite this expanding toolkit, real-world adoption of both implantable PA pressure monitoring and specialized non-invasive lung-fluid technologies remains limited. Implantable PA sensors are largely restricted to advanced HF programs and selected health-care systems because of device costs, implantation requirements, and the need for multidisciplinary infrastructure to act on frequent pressure data.[[2,5–7,13,19] Similarly, thoracic fluid monitoring systems are currently deployed in niche settings or pilot programs rather than at scale.[4,9,15,16,18] As a result, most patients across the ED, inpatient, and early post-discharge settings continue to be managed primarily using intermittent, indirect surrogates of congestion rather than objective hemodynamic data.[1–3,10,15,19–21] The proven benefits of pressure-guided management in the post-discharge setting suggest that bringing similar, non-invasive, cost-effective pressure monitoring capabilities into ED disposition and inpatient care could improve risk stratification, reduce unnecessary admissions and length of stay, and ultimately deliver both clinical and economic benefits.[2,5–7,13,19]

4 Non-invasive volume and pressure surrogates: successes and limitations

4.1 Conventional non-invasive surrogates of pressures

Traditional non-invasive markers such as symptoms, physical examination, natriuretic peptides, chest imaging, and echocardiography, have shown evidence of feasibility as non-invasive surrogates of cardiac and pulmonary pressures.[1,20,24] Nevertheless, their limitations in accurately and repeatedly capturing filling pressures are increasingly recognized:

Clinical signs (edema, rales, jugular venous distension) correlate only modestly with invasively measured pressures and may remain abnormal even after hemodynamic decongestion, or vice versa.[3,20,21]

Natriuretic peptide levels are prognostic and useful in diagnosis but are affected by renal function, age, atrial fibrillation, and body mass index, and may lag behind changes in intracardiac pressures.[1,24]]

Chest X-ray and lung ultrasound can detect pulmonary congestion and B-lines, and residual B-lines at discharge are associated with worse outcomes, but imaging is intermittent, operator-dependent, and not easily obtained multiple times per day.[10,12,16,18]

Echocardiographic Doppler indices (e.g., E/e' ratio, tricuspid regurgitation velocity, left atrial volume) can estimate left-sided filling pressures but have only moderate correlation with PCWP in many real-world settings and perform less well in atrial fibrillation, significant valvular disease, or marked atrial enlargement.[1,24]

Body weight, although widely used in both inpatient and outpatient HF management, remains an imperfect marker of congestion. Volume redistribution from the splanchnic to the central circulation can precipitate decompensation without large absolute changes in total body weight.[25] In a post hoc analysis of the ASCEND-HF trial, 26% of patients hospitalized for ADHF had essentially no in-hospital weight loss (change between −1 and +1 kg), and 8% actually gained ≥1 kg during the admission, even though all were treated with decongestive therapy.[2,21,24,25] While weight monitoring can be useful, it should not be relied on as the sole or primary indicator of congestion trajectory.

4.2 Non-invasive pressure surrogates that have underperformed

Several recent studies have explored whether routine non-invasive measurements could be combined with machine learning to predict intracardiac pressures. These efforts are instructive because they test whether existing data streams such as vital signs, body weight, and simple clinical variables, contain enough signal to approximate filling pressures without new technology.

In an analysis of more than 800 right heart catheterization procedures, van Ravensberg and colleagues used non-invasively collected parameters (including arterial blood pressure, oxygen saturation, heart rate and heart rate variability, weight, and body temperature) to predict PCWP.[11] They evaluated a wide range of regression and machine-learning models. All regression models had low explanatory power (maximum $R^2 \approx 0.04$), and classification models designed to distinguish normal from elevated PCWP achieved AUC values no higher than about 0.59, only slightly better than chance.[11] The authors concluded that conventional non-invasive measurements and their short-term variability show only weak correlation with actual filling pressures and are insufficient for reliable PCWP estimation.

Other non-invasive surrogates have shown mixed performance. Echocardiographic algorithms for estimating PCWP and pulmonary vascular resistance can be useful but lose accuracy in the presence of atrial fibrillation, significant valve disease, or marked atrial enlargement, and they require comprehensive imaging that is not easily repeated serially.[1,24] Cardiac MRI-based approaches to infer relative pressure gradients or PCWP from imaging features and clinical variables are promising in research settings, but they remain confined to specialized

Early-phase studies of multi-sensor chest devices, such as Acorai, suggest that non-invasive estimation of right- and left-sided filling pressures may be feasible ..

centres and are not suited to high-frequency bedside monitoring.[8] Experimental venous waveform devices and wrist-based systems have shown varying degrees of correlation with invasive measures in small studies, but broad validation and robust outcome data are lacking.

Collectively, these negative and neutral findings reinforce a key point: non-invasive surrogates cannot easily directly capture cardiac mechanical activity, intracardiac pressure waveforms, or pulmonary vascular dynamics, and may not provide the fidelity needed for day-to-day inpatient HF management.

5 Next-generation non-invasive cardiac and pulmonary pressure sensing

Against this backdrop, there is growing interest in technologies that can estimate intracardiac and pulmonary pressures non-invasively, repeatedly, and at the bedside. Several categories of investigational platforms are under study:

Multi-sensor chest devices that combine modalities such as seismocardiography (SCG), phonocardiography (PCG), photoplethysmography (PPG), electrocardiography (ECG), and thoracic bioimpedance, with machine-learning models trained against right heart catheterization data.[A1,A2]

Wearable or handheld venous waveform devices that analyze peripheral venous or arterial waveforms to infer PCWP or volume status.[13]

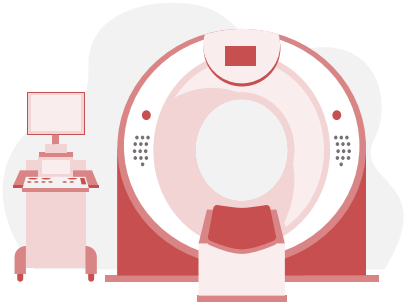
Advanced imaging pipelines that use cardiac MRI or 4D flow data, integrated with clinical variables, to estimate pressure gradients and filling pressures.[8]

Hybrid systems that integrate sensor data, imaging, and electronic health record variables into multimodal models.

Early-phase, single- and multicentre studies of multi-sensor chest devices suggest that non-invasive estimation of right- and left-sided filling pressures may be feasible, with errors approaching the variability seen between different invasive measurements in some settings. The CAPTURE-HF study was a large, 1600-patient, prospective, multicenter evaluation of Acorai's non-invasive, multi-sensor cardiac and pulmonary pressure estimation system in patients undergoing right heart catheterization, designed to compare non-invasive pressure estimates with invasive gold-standard measurements and to characterize performance across a broad spectrum of heart failure phenotypes.[A1] However, many systems remain investigational; large-scale validation against invasive gold standards, subgroup analyses across diverse HF phenotypes, and prospective outcome trials are required before they can be considered for routine use.

5.1 Principles for clinically meaningful congestion assessment tools

From the standpoint of inpatient cardiology and HF services, several design principles will determine whether non-invasive pressure sensing can transition from research to standard care:



1. Repeatability and ease of use. Bedside measurements must be obtainable by all healthcare professionals such as nurses or allied professionals within minutes, with clear guidance on sensor placement and automated quality checks. The system should be robust across body habitus, rhythm disturbances (e.g., atrial fibrillation), and respiratory variability, and suitable for serial measurements (e.g., daily or more often in unstable patients).[1]

2. Accuracy at clinically relevant thresholds. Performance should be evaluated not only by correlation coefficients but also by the ability to discriminate clinically meaningful pressure thresholds, such as PCWP ≥15 mmHg or RAP ≥10 mmHg, with high sensitivity and negative predictive value for ruling out dangerous congestion and adequate specificity for identifying patients likely to benefit from intensified therapy. [1,3,11]

3. Actionable and absolute interpretable outputs. Clinicians need outputs that translate into decisions, estimated congestion levels; probabilities or flags for elevated versus normal pressures; and trends over time (e.g. based on a hemodynamic congestion index number) rather than isolated values.[1]

4. Applicability across HF phenotypes. Hospitalized HF populations include HFrEF, HFmrEF, HFpEF, patients with pulmonary hypertension and predominant right ventricular failure, and those with significant valve disease or atrial fibrillation.[1,6,8] Clinically useful non-invasive pressure systems should be validated across this spectrum, with transparent reporting of subgroup performance.

5 Broad hemodynamic insights, including RAP and PCWP. Right and left-sided filling pressures are frequently discordant. Patients may have disproportionately elevated RAP (e.g., pulmonary hypertension, severe tricuspid regurgitation, predominant right-sided failure) or disproportionately elevated PCWP (e.g., early left-sided congestion).[1] Systems focusing on a single surrogate risk misclassifying these patients. Ideally, non-invasive platforms should provide estimates or composite indices reflecting both right- and left-sided congestion.[A1]

6 Minimal workflow friction and scalable economics. For hospitals, non-invasive systems must fit within existing workflows and budget structures. Multi-patient devices without per-use disposables, training requirements that fit into standard nursing education, and operating-expenditure-based pricing models will be paramount to facilitate adoption, especially when aligned with institutional goals around length of stay, readmission reduction, and value-based care.[2,6,19]

These principles can be illustrated by how a non-invasive pressure platform might be used in routine care:

A day-in-the-life implementation scenario

On a typical morning, ward nurses perform a 2–3 minute non-invasive hemodynamic scan at the bedside for each patient with heart failure, alongside vital signs and weight. The system automatically checks signal quality, combines multi-sensor inputs into an estimated filling-pressure or congestion index, and pushes the result and trend into the electronic health record. During multidisciplinary rounds, the HF team reviews these trends alongside symptoms, physical exam, natriuretic peptides, imaging, and traditional markers such as urine output—metrics that, while routinely used to guide diuretic therapy, often correlate poorly with true intracardiac pressures. By providing a direct, repeatable measure of congestion, a non-invasive pressure assessment can help clinicians more confidently adjust therapy, ensure patients reach an appropriate level of decongestion prior to discharge, and reduce both premature discharge and unnecessary prolonged stays. In the ED and early post-discharge settings, the same workflow supports risk stratification, admission avoidance where safe, and structured follow-up planning, without requiring invasive procedures or substantial changes to staffing models.

6 Non-invasive hemodynamics and in-hospital GDMT optimization

Given the high per-day costs of HF hospitalization, even modest reductions in LOS can yield substantial savings and free beds for other high-priority uses.

Beyond congestion and discharge decisions, an important potential use case for non-invasive pressure sensing is in supporting in-hospital and early post-discharge GDMT optimization. As STRONG-HF and related analyses have shown, rapid initiation and up-titration of evidence-based therapies in the weeks surrounding an HF hospitalization can significantly reduce death and rehospitalization, provided that patients are monitored carefully for hypotension, renal dysfunction, electrolyte disturbances, and recurrent congestion.[10,14]

In clinical practice, uncertainty about hemodynamic status often leads to cautious or delayed therapy changes. A patient who appears clinically improved but has persistent elevation in PCWP and RAP may decompensate if vasodilators or neurohormonal antagonists are aggressively up-titrated. Conversely, a patient who still has mild dyspnea or edema but whose filling pressures have normalized might safely tolerate more intensive GDMT, and further escalation of diuretics could be unnecessary or even harmful.[1,3,10,21]

Validated non-invasive pressure measurements could provide an additional layer of information in this context. Serial estimates of RAP and PCWP could help clinicians: (1) identify patients who remain hemodynamically congested despite apparent clinical improvement; (2) determine when it is safe to prioritize GDMT intensification over further decongestion; and (3) monitor the hemodynamic impact of therapy changes in the early post-discharge period.[A1] Such measurements would complement, not replace, clinical assessment, biomarkers, and imaging.

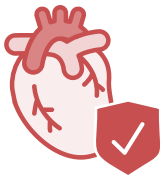
Formal evaluation of pressure-guided GDMT strategies will be essential. Key questions include whether non-invasive hemodynamic guidance increases achieved GDMT doses, reduces adverse events, or improves outcomes compared with current practice, and how best to combine pressure-guided and natriuretic peptide–guided approaches.[10,14] Nonetheless, conceptually, coupling precise congestion assessment with rapid, guideline-concordant therapy intensification is highly aligned with contemporary HF management paradigms.

7 Economic and workflow implications

Residual congestion at discharge is a major driver of 30- and 90-day readmissions... Each HF readmission carries direct costs and potential penalties under readmission reduction programs.

From a health-system perspective, the potential value of better inpatient hemodynamic management stems from three main domains:

1. Reductions in length of stay (LOS);



2. reductions in early readmissions and avoidance of unnecessary admissions; and

3. Long-term benefits of optimized GDMT.[2,6,10,19]

First, improved precision in decongestion and discharge readiness may shorten hospital stays for a subset of patients. Given the high per-day costs of HF hospitalization, even modest reductions in LOS can yield substantial savings and free beds for other high-priority uses.[2,19] Early-supported discharge and virtual ward programs for heart failure have already demonstrated meaningful reductions in the duration of the index hospitalization. In a technology-enabled heart failure virtual hospital in the UK, early discharge to a virtual ward supported by daily remote monitoring and specialist review reduced mean acute length of stay from 9.1 to 5.8 days (a 36% relative reduction) compared with contemporaneous in-hospital controls, while maintaining low readmission rates and excellent patient satisfaction.[35] More broadly, a recent systematic review of inpatient-level care at home and virtual wards found that, across multiple acute conditions (including heart failure), technology-enabled "hospital at home" models can deliver similar or shorter lengths of stay and comparable mortality and readmission rates versus traditional inpatient care.[36]

Objective, trendable indices can be embedded into nurse-driven protocols…reducing practice variability and overburdened clinical workflows.

Second, residual congestion at discharge is a major driver of 30- and 90-day readmissions.[3,10,12,16,18,21,22] Each HF readmission carries direct costs and, in some jurisdictions, potential penalties under readmission reduction programs. In parallel, improved hemodynamic risk stratification in the emergency department could help avoid some initial HF admissions altogether by safely routing lower-risk, hemodynamically stable patients to observation or hospital-at-home pathways instead of routine inpatient stays. Strategies that reliably reduce residual congestion and support early, structured follow-up, potentially informed by non-invasive pressure or lung-fluid metrics, are therefore likely to have an outsized impact on both patient outcomes and hospital margins.[2,3,10,19,21]

Third, by making hemodynamic information more accessible, non-invasive pressure sensing could help HF specialists and hospitalists manage larger and more complex caseloads without proportional increases in specialist time. Objective, trendable indices can be embedded into nurse-driven protocols, standardized order sets, and multidisciplinary rounds, reducing practice variability and cognitive load. Over time, such tools may facilitate new care models such as early-discharge pathways with structured, data-driven follow-up.[1,2,6,10,19]

Realizing these benefits will require careful implementation: integrating new measurements into electronic health records, defining how they influence decision pathways, training staff, and aligning technology deployment with value-based payment models. Equity considerations will also be important to ensure that innovations in hemodynamic monitoring narrow, rather than widen, existing disparities in HF care.[1,2,6]

Illustrative operational use cases

Example 1 – Earlier discharge in a defined subset of lower-risk patients

In current practice, discharge timing for hospitalized HF patients is often driven by symptoms, weight, and natriuretic peptides, despite evidence that residual congestion is common at the time of discharge. In a model that incorporates non-invasive pressure trends, a subset of hemodynamically stable patients with improving congestion indices and low estimated filling pressures could be identified as candidates for earlier discharge, with structured follow-up in a virtual ward or hospital-at-home program. Even modest reductions in length of stay in this defined cohort translate into meaningful bed-day savings and increased capacity for higher-acuity admissions.

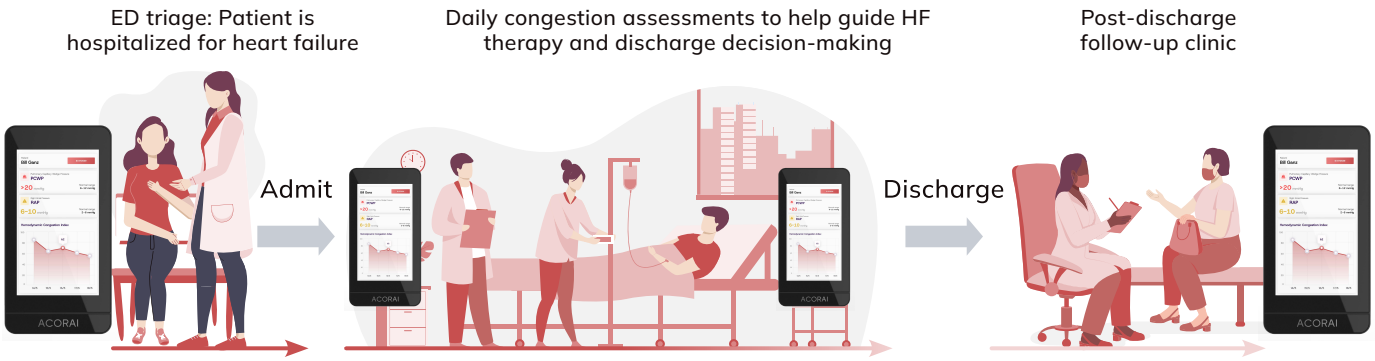


Figure 3. Heart failure care journey with potential touchpoints for non-invasive pressure assessment from ED triage through inpatient decongestion and early post-discharge monitoring.

Example 2 – More confident use of observation and hospital-at-home from the ED

ED teams frequently admit patients with suspected acute decompensated HF because they cannot confidently distinguish high-risk congestion from milder, isolated fluid overload. With access to a repeatable, non-invasive congestion index at the point of care, patients with stable vitals, reassuring hemodynamic profiles, and appropriate social support could be preferentially routed to observation units or hospital-at-home pathways rather than multi-day inpatient stays. This shift does not replace clinical judgment, but it provides an additional objective signal to support risk stratification, enabling more efficient use of inpatient beds and nursing resources.

Example 3 – Nurse-driven titration protocols on the ward

Today, diuretic and fluid-management decisions are often made ad hoc by individual clinicians, leading to variability in practice and workload. Embedding non-invasive pressure thresholds or congestion bands into nurse-driven protocols (for example, intensifying diuresis when indices remain elevated despite symptom improvement, or de-escalating when pressures normalize) can standardize care across teams. For service-line leaders, such protocols offer a clearer link from improved hemodynamic insight to more predictable LOS, fewer readmissions related to inadequate decongestion, and better alignment of staffing with patient acuity.

8 Outlook

Figure 3. Illustrative user interface of a cardiac and pulmonary pressure sensing device in development by Acorai and an overview of Acorai's multi-modal SAVE Sensor System hardware

The convergence of rising HF burden, persistent residual congestion, pressures on hospital capacity, and the push for value-based care highlights the need for real-time, scalable hemodynamic insights.

Next-generation non-invasive cardiac and pulmonary pressure sensing will ultimately:

- → Integrate seamlessly into ED and inpatient workflows
- → Enable precision diuretic therapy
- → Accelerate GDMT optimization
- → Improve discharge planning
- → Reduce avoidable cost and variability
- → Provide a new standard for evidence-based congestion management

As clinical validation grows and reimbursement pathways mature, these technologies will become a foundational element of modern HF care

Evidence from implantable PA pressure monitoring, lung-fluid technologies, guideline documents, and trials such as STRONG-HF all point in the same direction: when HF care is aligned more closely with underlying hemodynamics, rather than relying solely on symptoms and conventional surrogates, patients experience fewer decompensations and better outcomes.[1,4–8,10,13,18] At the same time, experiences with conventional surrogates and machine-learning approaches based on routine non-invasive measurements demonstrate that many simple proxies lack the fidelity needed for reliable hemodynamic guidance.[11,20,24]

Next-generation non-invasive cardiac and pulmonary pressure sensing aims to bridge this gap by providing repeatable, bedside-accessible estimates of key hemodynamic parameters such as RAP and PCWP. These technologies remain investigational, and robust evidence from multicenter validation studies and prospective outcome trials is essential before they can be fully integrated into guidelines or routine care.[A1] Nonetheless, their

Residual congestion at discharge is common and strongly associated with worse outcomes.

potential to support more precise decongestion, safer and faster GDMT optimization, and more efficient use of inpatient resources makes them an important area for ongoing research and collaboration among clinicians, engineers, and health-system leaders.

For cardiologists and HF teams, key near-term opportunities include deepening familiarity with hemodynamic-guided care pathways, participating in clinical trials of emerging non-invasive technologies where appropriate, and advocating for multidisciplinary models that integrate congestion assessment, GDMT optimization, and structured follow-up. Non-invasive cardiac and pulmonary pressure sensing sits at the intersection of cardiovascular medicine, sensing technology, and artificial intelligence, and is directly aligned with health-system priorities around value-based care, capacity, and workforce sustainability. By transforming intracardiac pressures from a rarely measured invasive endpoint into a safe, repeatable bedside and home metric, this class of technology has the potential to anchor a new, scalable service line in heart failure—one that addresses a large, durable unmet need while creating a clear path for evidence-based adoption by clinicians, health systems, and industry partners.[1,2,5–8,10,19]

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Appendix.
Glossary of key terms and abbreviations

HF – Heart failure
A clinical syndrome in which the heart cannot pump enough blood to meet the body's needs, leading to symptoms such as shortness of breath, fatigue, and fluid retention.

AHF – Acute heart failure
A sudden or progressive worsening of heart failure symptoms, often requiring urgent evaluation in the emergency department and frequently leading to hospitalization.

HFrEF – Heart failure with reduced ejection fraction
Heart failure in which the left ventricle's pumping function is reduced (typically LVEF <40%), often treated with a well-defined set of guideline-directed therapies.

HFmrEF – Heart failure with mildly reduced ejection fraction
Heart failure with a moderately impaired ejection fraction (often defined as LVEF 40–49%), sharing features of both reduced and preserved EF.

HFpEF – Heart failure with preserved ejection fraction
Heart failure in which the ejection fraction is normal or near-normal, but the heart is stiff or unable to relax properly, leading to congestion and symptoms despite "normal" pump function.

LVEF – Left ventricular ejection fraction
The percentage of blood pumped out of the left ventricle with each heartbeat, commonly used to classify heart failure and guide therapy.

GDMT – Guideline-directed medical therapy
Evidence-based medications recommended by professional society guidelines for the treatment of heart failure (for example, ACE inhibitors or ARNI, beta-blockers, MRAs, and SGLT2 inhibitors).

ED – Emergency department
The hospital-based unit where patients with acute symptoms, including suspected acute heart failure, are first evaluated and triaged.

LOS – Length of stay
The number of days a patient spends in the hospital during a given admission; a key metric for hospital capacity and cost.

RAP – Right atrial pressure
A pressure reflecting the filling status of the right side of the heart and systemic venous congestion; often used as a surrogate for volume status.

PCWP – Pulmonary capillary wedge pressure
An invasive pressure measurement obtained with a pulmonary artery catheter that closely approximates left atrial and left-sided filling pressures; a key hemodynamic marker of congestion.

PA pressure / PAP – Pulmonary artery pressure
Pressure measured in the pulmonary artery, reflecting the load on the right ventricle and, indirectly, left-sided pressures when interpreted with other data.

RHC – Right heart catheterization
An invasive procedure in which a catheter is advanced into the right heart and pulmonary artery to measure pressures and cardiac output; the gold standard for hemodynamic assessment.

Residual congestion
Persistent fluid overload or elevated filling pressures at or after hospital discharge, even when symptoms and weight have improved; associated with higher rates of re-hospitalization and mortality.

Virtual ward / hospital-at-home
Care models in which patients receive intensive monitoring and treatment at home or in an observation setting, with hospital-level oversight but without occupying an inpatient bed.

Non-invasive hemodynamic / congestion index
A composite metric derived from external sensors that estimates cardiac filling pressures or overall congestion without the need for an indwelling catheter, designed to be repeatable at the bedside.

PA catheter / Swan-Ganz catheter
A balloon-tipped catheter inserted via a central vein into the pulmonary artery, used to measure RAP, PA pressures, PCWP, and cardiac output in selected patients.