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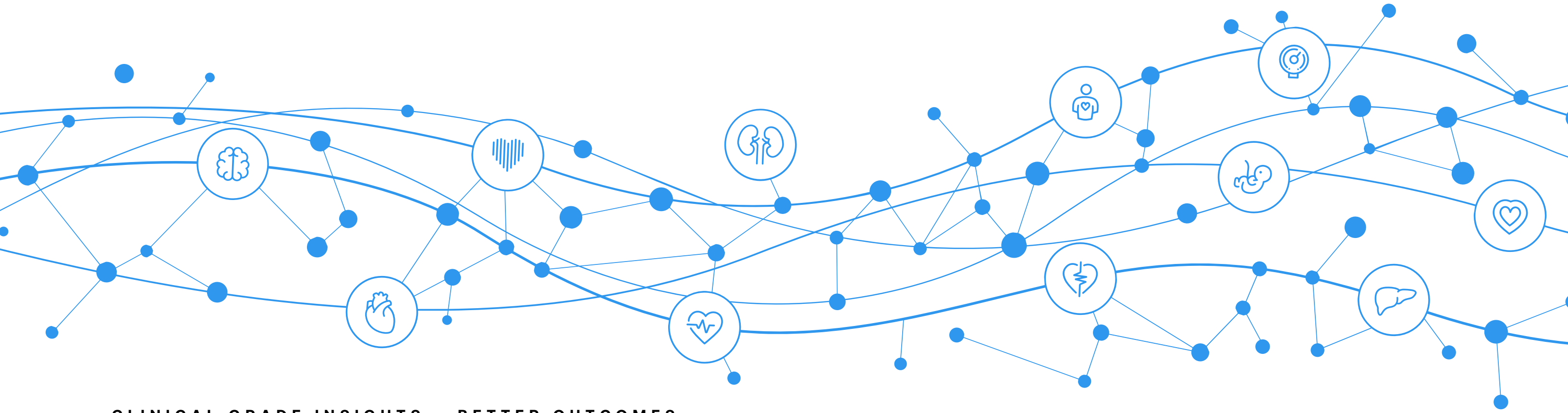
Health

Post-Discharge Management of Patients with Acute Decompensated Heart Failure with non-invasive Central Aortic Pressure: A Clinical Guide for Cardiology Clinics

Clinical Insights

- Incorporating central aortic pressure and brachial blood pressure measurements into HF management leads to better patient outcomes, reduced risk of rehospitalization, and enhanced quality of life.
- Central aortic pressures correlate strongly with key hemodynamic parameters such as ejection fraction, cardiac output, stroke volume, and LV dp/dt. Monitoring changes in central pressures can identify positive treatment responses, indicating improvements in cardiac function.
- Using both central aortic pressure and brachial blood pressure measurements enables more precise adjustments to guideline-directed medical therapy, help in tailoring therapy to individual needs, improving functional capacity, and preventing disease progression.
- The integration of central aortic pressure and brachial blood pressure measurements in remote patient monitoring enhances continuous and comprehensive oversight. This is especially important for patients recently discharged from the hospital, who are at higher risk for rehospitalization and adverse events.
- FDA-cleared monitors capable of measuring both brachial and central BP are now commercially available, making it easier to adopt these measurements in heart failure management at point-of-care and home-based settings.



At-a-Glance Guide to Heart Failure Management: Central and Brachial BP Insights

A tailored approach incorporating both central and brachial BP ensures that therapy is optimized according to the specific hemodynamic profile of each patient, improving treatment outcomes and reducing the risk of complications.

Scenario	Treatment Considerations
Normal CABP 110-120 mmHg Hypertensive CABP >120 mmHg Hypotension CABP <110	
High Central Aortic Pressure & High Brachial Blood Pressure **Example:** CABP >120 and Brachial BP > 130 mmHg	**Normal or high pressures in this case can represent a high afterload state** Consider titration of GDMT to reduce central and brachial blood pressure.
Normal to Low Central Aortic Pressure & Low Brachial Blood Pressure **Example:** CABP 105 and Brachial BP 110 mmHg.	**In the presence of low brachial pressure, normal to low central aortic pressure may imply that GDMT is at target doses** Consider close follow up to monitor if hypotension persists or BP lowers further
Low Central Aortic Pressure & Low Brachial Blood Pressure **Example:** CABP <100 and Brachial BP <110 mmHg	**Hypotension in this case may be due to poor cardiac function, low cardiac output, and/or high afterload.** 1. Reduce GDMT/diuretics if doses may be too high. 2. Consider right heart catheterization and/or co-management with advanced HF specialist for assessment of CRT candidacy, CRT optimization, mitral regurgitation repair, CardioMEMs, assess atrial fibrillation burden, LVAD/Tx candidacy, palliative care, other. May require closer clinical follow up, more frequent clinic visitations, or hospitalization for hemodynamic guided therapy.
Normal Central Aortic Pressure & High Brachial Blood Pressure **Example:** CABP 110-120 and Brachial BP > 140 mmHg	**High brachial blood pressure in this case may be due to vascular disease and stiffness of the peripheral arteries.** 1. Consider lowering diuretics if the cause of low central blood pressure is intravascular depletion. 2. When appropriate adjust GDMT. 3. Consider a work-up for peripheral arterial disease, if indicated.

*Central aortic and brachial blood pressure measurements should be individualized based on the patient's cardiac function, symptoms, and GDMT treatment strategy. The examples provided above are meant to illustrate the patterns of high and low CABP and brachial BP, and those that may be observed during clinical care.

Introduction

The management of heart failure (HF), particularly following hospital discharge for acute decompensated heart failure (ADHF), requires meticulous attention to detail and precise adjustments in treatment. One of the cornerstone strategies in this management is the use of guideline-directed medical therapy (GDMT). However, the effectiveness of GDMT hinges on accurate and reliable blood pressure (BP) measurements, which serve as critical indicators of a patient's hemodynamic status and response to therapy. While brachial BP measurements are used in clinical practice, it is broadly accepted that these measurements might not be sufficiently accurate in the context of advanced HF, or informative to individualize GDMT approaches that lowers HF-related risk.[1,2]

For the following reasons, there is a growing recognition of the need to incorporate accurate hemodynamic measurements such as central aortic pressure (CAP) and central aortic pulse pressure (CAPP) in the management of heart failure:

- Unlike brachial BP, CAP and CAPP are directly related to ejection fraction, cardiac output, stroke volume, and LV dp/dt, key hemodynamic parameters of cardiac function in HF
- These central pressures provide a more comprehensive assessment of the cardiovascular status and have demonstrated/shown significant prognostic implications that identify high-risk HF patients.
- For instance, lower CAP and CAPP are associated with reduced LV function and poorer outcomes in both heart failure with reduced ejection fraction (HFrEF) and heart failure with preserved ejection fraction (HFpEF)
- Central pressure can augment clinical decisions including HF treatment approaches, GDMT, and device-based interventions to improve patient outcomes
- Central blood pressures may serve as a usable surrogate when imaging or invasive measurements are not readily available such as in resource constrained clinics or for patients in rural geographies.

2024 ACC Expert Consensus on Ten Pivotal Issues in HFrEF

How to implement GDMT...

1. How to initiate, add, or switch therapies with consideration of newer evidence-based guideline-directed treatments for HFrEF.
2. How to achieve optimal therapy given multiple drugs for HF, including augmented clinical assessment (eg, imaging data, biomarkers, and filling pressures) that may trigger modifications in guideline-directed therapy.

How to address challenges with...

3. When to refer to an HF specialist.
4. How to enhance care coordination.
5. How to improve medication adherence.
6. How to tailor treatment in specific patient cohorts: African-American patients, older adults, and patients with frailty.
7. How to manage patients' costs and increase access to HF medications.

How to manage...

8. How to manage the increasing complexity of HF alist.
9. How to manage common comorbidities.
10. How to integrate palliative care and the transition to hospice care.

The Limitations of Brachial Blood Pressure in Heart Failure

Brachial blood pressure measurements, while convenient and non-invasive, have notable limitations in patients with heart failure. In individuals with advanced HF, including patients with severe cardiomyopathy, greater left ventricular (LV) diastolic dysfunction, and concomitant conditions such as cardiorenal failure and atrial fibrillation, brachial BP readings may be inaccurate due to several factors:

1. **Pressure Amplification:** As blood travels from the central aorta to the peripheral brachial artery, the pressure wave undergoes amplification and alteration (Figure **1**). This phenomenon is influenced by the stiffness of the arteries and wave reflections. In patients with heart failure, especially those with increased arterial stiffness, this amplification can cause a significant disparity between central and brachial pressures. Consequently, brachial BP may not accurately reflect the true hemodynamic status of the patient.

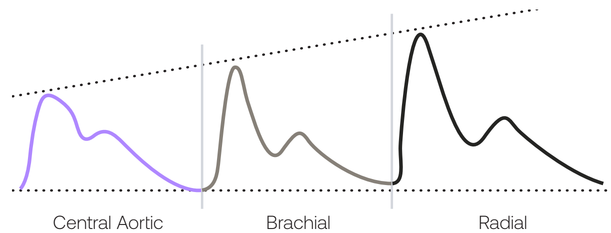


Figure 1: Illustration of 'amplification phenomenon', where the amplitude of the pressure waveform increases the further away from the heart. Published from Nichols et al.*

2. **Variability in Hemodynamics:** Patients with severe cardiomyopathy and/or LV diastolic dysfunction often experience significant blood pressure variability and alterations in hemodynamics.[3] In such conditions, cardiac performance can be reduced leading to fluctuations in arterial waveform parameters and blood pressure that brachial measurements alone may not capture accurately, or precisely enough to guide treatment recommendations.[4]

3. **Influence of Concomitant Conditions:** Concomitant conditions such as cardiorenal failure and atrial fibrillation further complicate the accuracy of brachial BP measurements. In cardiorenal failure, fluid retention, volume overload, and arterial stiffness are common, which cause increases in peripheral vascular resistance. The resulting brachial pressure measurements may not be representative of central hemodynamics such as central aortic blood pressure, cardiac output or stroke volume. Atrial fibrillation and beat-to-beat variability can also result in inconsistent brachial BP readings, particularly in the presence of low ejection fraction or low cardiac output.

4. **Peripheral Arterial Stiffness:** In heart failure patients, especially those with vascular disease, peripheral arterial stiffness is prevalent. This stiffness increases pulse wave velocity and alters the pressure wave as it travels to the brachial artery. The resultant pressure amplification effect widens the gap between central aortic and brachial BP leading to potential underestimation or overestimation of the patient's blood pressure if relying solely on brachial measurements.[5]

Limitations of Brachial Blood Pressure: Use Case Examples

Sarcopenia, Cachexia, and Deteriorating LV Function:

When a HF patient is monitored remotely in home-based settings, the brachial BP measurements can vary considerably. Factors such as changes in muscle mass, sarcopenia, or cachexia can result in improper cuff placement, inconsistent measurement techniques, and contribute to inaccurate readings. In patients with deteriorating LV function, these inaccuracies are amplified, making it challenging to rely on brachial BP for guiding treatment decisions.

Identifying GDMT Responders:

The utility of brachial BP in identifying responders to HF GDMT is also limited due to its low sensitivity to measure incremental changes in cardiac function resulting from HF therapies.* These limitations hinder the identification of patients who are responding to treatment, especially in high-risk patients where cardiologists rely on ambulatory BP measurements taken at home. This issue is particularly significant for patients recently hospitalized for ADHF where timely and accurate treatment decisions based on ambulatory, brachial BP measurements are crucial to stabilize cardiac function, and to reduce the risk of rehospitalization. The Clinical Role of Central Aortic Pressures in Heart Failure

"New methods that assess arterial pressure and flow dynamics, beyond focus on conventional upper-arm blood pressure, are needed."

The *Lancet Commission on hypertension, 2016*

Advantages of Central Aortic Pressure in Heart Failure Management

Unlike traditional brachial blood pressure measurements, which can be limited by peripheral amplification and variability, CAP and CAPP provide a direct and accurate reflection of the hemodynamic forces at play within the central arteries. The differences in the amplification of systolic BP are not readily apparent from the brachial systolic and diastolic BPs. Waveform examples from two patients are shown in Figure 2**Error! Reference source not found.**[6] Figure **2**-A depicts an elderly healthy woman, the difference in systolic pressure at the proximal aorta compared with the brachial artery may be as little as 4 mmHg to 6 mm Hg. Whereas Figure **2Error! Reference source not found.**-B depicts a young healthy man, the difference may be more than 25 mmHg.

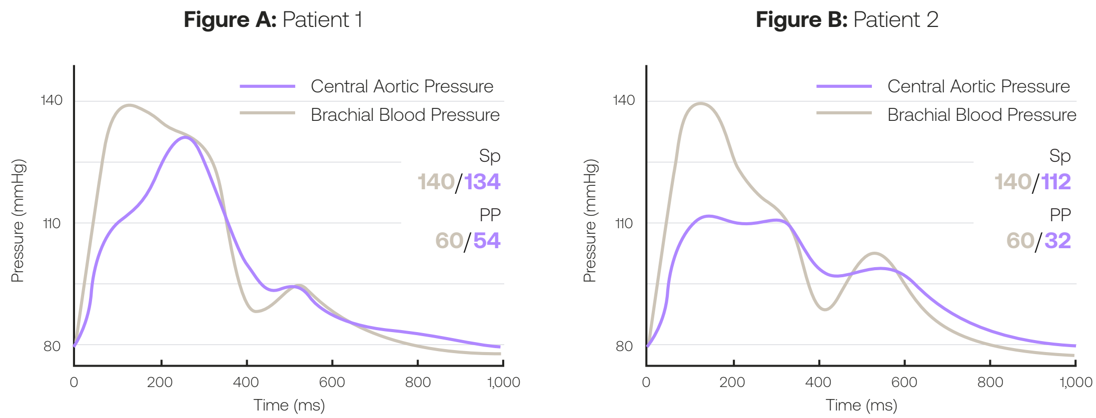


Figure 2: Two patients with equivalent brachial pressures but with significantly different central arterial pressure waveforms. The difference in waveform shapes, due to differences in arterial stiffness and the effects of wave reflections.

In HF, CAP and CAPP correlate strongly with key hemodynamic parameters including:[7]

- Ejection fraction
- Cardiac output
- Stroke volume, and;
- LV dp/dt.

The prognostic value of CAP and CAPP is especially significant in heart failure management. Lower CAP and CAPP are associated with reduced left ventricular function and predict poorer outcomes in heart failure patients. This association holds true for both HFpEF and HFrEF in Figure 3, where lower CAP and CAPP indicate more severe disease states and a higher risk of adverse events, including hospitalization and mortality.

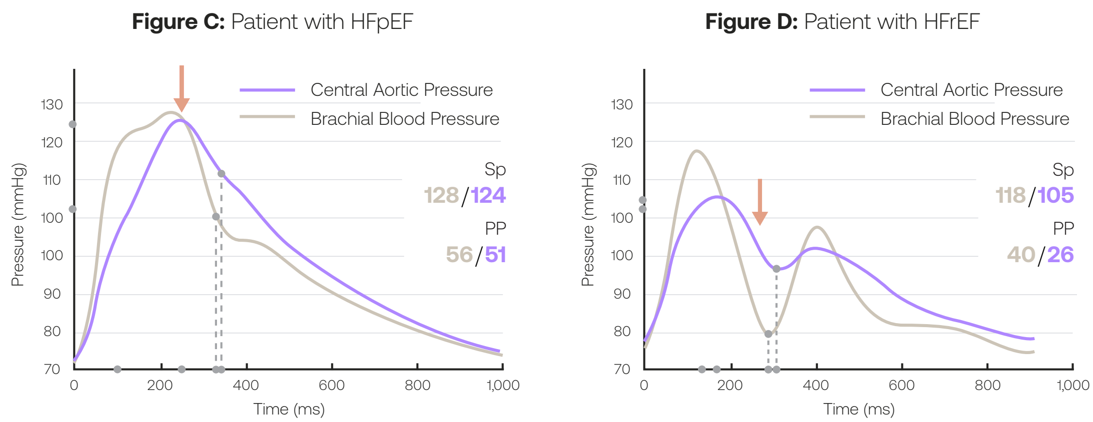


Figure 3: Waveform examples from patients with HFpEF and HFrEF.

In HFpEF, lower CAP and CAPP indicate advanced diastolic dysfunction and correlate with impaired exercise tolerance and worse clinical outcomes.[8] When LV pump function is preserved, the reflected aortic pulse wave induces a late systolic pressure peak in the pressure waveform (Figure **3**-C), augmenting aortic pressure in mid-to-late systole. These features are prominent in patients with HFpEF and may be useful in the diagnostic workup of the condition. In symptomatic HFpEF patients with exertional symptoms and exercise intolerance, measures of cardiac function including central aortic pressure and central hemodynamics correlate well with tissue doppler imaging parameters of increased LV filling pressure.[9]

In HFrEF, the LV's reduced ability to generate adequate cardiac output is often reflected in lower central pressures, indicating the severity of the condition and the effectiveness of therapeutic interventions. In these patients, wave reflections are truncated (Figure **3**-D) and correspond to low forward flow and a shortening of ejection duration indicating reduced cardiac output and stroke volume. The relative decrease in blood pressure is more accurately captured by central aortic pressure measurement (105/79 mmHg) than it is by brachial pressure (118/78 mmHg). In such patients, hemodynamic measurements of low cardiac output are identified in pulse wave analysis of wave reflection (i.e., augmentation index and augmentation pressure) and are typically low due to low stroke volume and high afterload.[12]

Optimizing central pressures correlate with enhanced cardiac output and reduced heart failure symptoms, highlighting the importance of targeting central hemodynamics in treatment.[10] The combination of CAP, CAPP, and brachial BP is particularly valuable when used to optimize GDMT, and to precisely stratify high risk HF patients. CAP and CAPP can identify changes in cardiac function that brachial BP might miss, such as improvements in left ventricular performance and reductions in afterload, indicating a positive response to treatment. By monitoring both central and peripheral pressures, treating cardiologists can adjust medications more precisely, ensuring that therapy is neither under- nor over-prescribed.

Remote Monitoring of Central Aortic Pressure to Improve HF Outcomes

Effective management of HF, particularly after discharge ADHF, hinges on precise adjustments in GDMT and accurate BP measurements. While brachial BP has traditionally been used, their limitations in advanced HF necessitate the incorporation of CAP and CAPP measurements. These central pressures provide a more accurate and comprehensive assessment of cardiac function and hemodynamic status, which is critical for effective HF management.

Central Aortic and Brachial Pressure after Hospital Discharge for ADHF:

The detailed information provided by both CAP and brachial BP enables more precise tailoring of treatment after hospital discharge for ADHF. For instance, HF patients with high CAP and high brachial BP require treatment focusing on reducing afterload and optimizing diuretic therapy. In contrast, HF patients with low CAP and low brachial BP may identify a high-risk patient who requires adjustments to GDMT to support cardiac function, closer clinical follow-up, and/or co-management with heart failure specialists. This tailored approach ensures that therapy is responsive to each patient's specific hemodynamic profile, and to enhance the effectiveness of medical and device-based treatments that improve patient outcomes.

Central Aortic and Brachial Pressure Remote Monitoring in HF:

The use of CAP and brachial BP in remote patient monitoring represents a significant advancement in heart failure management. Patients can be monitored continuously and comprehensively from their homes, reducing the need for frequent hospital visits while maintaining close oversight of their condition. This approach not only improves patient convenience and compliance but also allows for timely interventions based on real-time physiologic data, further enhancing heart failure management, and potentially reducing healthcare costs. Integrating central aortic pressure and brachial blood pressure measurements into heart failure management provides a robust framework for optimizing treatment, stratifying risk, and tailoring interventions to individual patient needs leading to better outcomes and reduced risk of rehospitalization.

Non-invasive Assessments of Central Aortic Pressure

Non-invasive assessments of CAP and CAPP represent a significant advancement in cardiovascular diagnostics, providing a safer and more convenient alternative to traditional invasive methods. CAP and CAPP can be determined by analyzing the peripheral arterial waveform obtained from either the brachial artery using an oscillometric cuff or the radial artery using a tonometer. These methods generate a waveform that is processed through a general transfer algorithm to produce a central pressure profile, from which CAP and CAPP are extracted.

Several devices are available for the measurement of CAP & CAPP. These devices have, in general, been validated in catheterization laboratories and when accurately calibrated have been shown to be within 1 mmHg to 2 mmHg of the actual pressure in the proximal aorta.[11] These non-invasive devices typically feature user-friendly interfaces and portable designs, making them suitable for both clinical and home use. Many devices also include integrated data management systems, enabling seamless tracking and analysis of patient data over time.

Continual innovation in this field promises to further enhance device performance and functionality, solidifying non-invasive CAP assessment as an essential tool in modern cardiovascular care. The widespread availability of these devices enables their use across various healthcare settings, from primary care clinics to specialized cardiovascular centers. This broad accessibility facilitates early detection and improved management of patients with heart failure, ultimately reducing the reliance on invasive procedures and lowering healthcare costs.

Integration of Central Aortic Pressure into Standard of Care

Using CAP and brachial BP measurements at point-of-care and in remote patient monitoring provides a comprehensive strategy for managing HF. This dual-measurement approach (CAP + brachial BP) offers a complete picture of a patient's cardiovascular status, enabling precise treatment decisions and better risk stratification. Post-ADHF hospitalization, central pressure identifies patients at higher risk facilitating timely interventions towards reducing the likelihood of rehospitalization.

The use of non-invasive CAP devices at the point-of-care aligns with CPT code 93050, issued in 2016, to provide physicians with additional information for managing blood pressure beyond the current brachial BP goals. Additionally, CPT codes for remote patient monitoring (RPM), such as 99453, 99454, 99457, 99458, and 99091, support the integration of these non-invasive CAP and CAPP measurements into routine patient care. These RPM codes facilitate reimbursement for the setup, supply, and daily transmission of physiological data, as well as the management and interactive communication with patients.

CPT Code 93050: Arterial pressure waveform analysis for assessment of central arterial pressures, includes obtaining waveform(s), digitization, and application of nonlinear mathematical transformations to determine central arterial pressures and augmentation index, with interpretation and report, upper extremity artery, non-invasive.

CPT Code 9945x: Remote monitoring of physiologic parameter(s) (eg, weight, blood pressure, pulse oximetry, respiratory flow rate). These codes cover the initial setup and patient education on monitoring equipment, the monthly supply of devices and data transmission, and the monthly patient management and communications. This framework ensures financial support for comprehensive and continuous remote patient monitoring and management.

CPT Code 99091: Collection and interpretation of physiologic data (eg, ECG, blood pressure, glucose monitoring) digitally stored and/or transmitted by the patient and/or caregiver to the physician or other qualified health care professional, qualified by education, training, licensure/regulation (when applicable) requiring a minimum of 30 minutes of time, each 30 days

The integration of CAP and brachial BP into routine HF management represents a significant advancement to improve patient outcomes, enhance quality of life, and to reduce healthcare costs. By enabling continuous and comprehensive home-based monitoring, these dual measurements allow for early detection of changes in cardiac function, facilitating timely and precise treatment adjustments. This proactive approach helps prevent the progression of HF, reduces the incidence of acute decompensations, and lowers the risk of rehospitalization, thereby improving patient outcomes and enhancing their quality of life.

Moreover, the economic benefits are substantial. Continuous home-based monitoring reduces the need for frequent hospital visits and costly interventions. The use of CPT codes for remote patient monitoring (RPM) supports the financial viability of these comprehensive HF management programs by ensuring reimbursement for essential services. This integration not only optimizes therapy by tailoring treatment plans to each patient's unique hemodynamic profile but also empowers patients to take an active role in managing their condition, leading to better health outcomes and reduced healthcare costs.

About CONNEQT Health

CONNEQT Health pioneered a biosensing technology that has been clinically validated and FDA-cleared to noninvasively measure vascular biomarkers representing key indicators of vascular health. The indicators include, but not limited to, central BP, arterial stiffness, vascular age, and heart stress. Named SphygmoCor®, the technology has been deployed in healthcare systems and clinical trials to measure vascular health.

The SphygmoCor technology enables a new paradigm in the diagnosis and management of hypertension and cardiovascular diseases that is increasingly decentralized and personalized. When combined with cloud-based data analytics, our suite of FDA-cleared medical devices enables key stakeholders throughout the healthcare ecosystem to obtain valuable health information not accessible from standard brachial blood pressure monitors.

Learn more at conneqthealth.com.

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