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Review Article

Emerging Role of ambulatory ECG monitoring in the Diagnosis of heart failure with reduced ejection fraction

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Abstract

Background: HFrEF carries arrhythmic and autonomic abnormalities, silent atrial fibrillation, nonsustained ventricular tachycardia, excessive ectopic burden, depressed heart rate variability, that a resting ECG cannot capture.

Objective: This review synthesizes evidence on ambulatory ECG monitoring, spanning Holter recording, patch monitors, and implantable loop recorders, as a diagnostic and risk-stratification tool in HFrEF.

Methods: We synthesized cohort studies, randomized trials, guideline documents, and device-validation studies on continuous rhythm surveillance, arrhythmia burden, autonomic indices, and clinical application in reduced ejection fraction heart failure.

Findings: Monitoring duration is the dominant determinant of yield; extended patch and implantable recorders detect substantially more fibrillation and ectopy than a single 24-hour study, ectopic burden and heart rate variability independently track with dysfunction and mortality, and society guidelines embed ambulatory ECG across diagnosis, risk stratification, and device candidacy.

Conclusions: Ambulatory ECG monitoring is now a central, guideline-endorsed component of the HFrEF diagnostic pathway, its value maximized when duration matches the clinical question and findings are read alongside ejection fraction and clinical status.

Keywords: ambulatory ECG monitoring; heart failure with reduced ejection fraction; Holter monitoring; arrhythmia detection; heart rate variability

1. Introduction

Heart failure with reduced ejection fraction (HFrEF) is defined by a left ventricular ejection fraction of 40% or less with signs and symptoms of congestion, and remains a leading cause of hospitalization and mortality worldwide [1]. Diagnosis has traditionally rested on clinical examination, natriuretic peptide measurement, and echocardiographic ejection fraction, with the 12-lead electrocardiogram (ECG) relegated to a supporting role, useful for bundle-branch block, prior infarction, or overt arrhythmia at a single moment, but blind to everything between office visits [2,3]. That blindness matters because HFrEF is a disease of electrical as well as mechanical instability, and many abnormalities driving diagnosis and treatment selection, nonsustained ventricular tachycardia, silent atrial fibrillation, excessive ectopic burden, depressed heart rate variability, are intermittent or continuous phenomena a ten-second snapshot cannot capture [4].

Ambulatory ECG monitoring, spanning conventional 24- to 48-hour Holter recording, longer-duration adhesive patch monitors, and implantable loop recorders, closes this gap by recording cardiac electrical activity continuously over days to years. Its role in HFrEF has expanded from a niche tool for palpitations to a central component of diagnostic work-up, arrhythmia risk stratification, and device-therapy selection [5]. This review synthesizes the evidence for ambulatory ECG monitoring in HFrEF diagnosis, covering monitoring technology, the arrhythmic and autonomic markers it reveals, its guideline integration, and its practical limitations.

2. Pathophysiological rationale for continuous rhythm surveillance

The electrical substrate of HFrEF differs fundamentally from a structurally normal heart. Myocardial fibrosis, chamber dilation, and neurohormonal activation together favor both reentrant ventricular arrhythmia and

disordered autonomic tone, and each leaves a signature only continuous recording can reliably detect. Nonsustained ventricular tachycardia, three or more consecutive ventricular beats above 100 beats per minute lasting under 30 seconds, occurs in a substantial proportion of patients with severe left ventricular dysfunction and was shown by the GESICA investigators to independently predict mortality in severe heart failure after adjustment for ejection fraction and functional class [6]. Because these runs are typically asymptomatic and self-terminating, a resting ECG will almost never capture one; true prevalence only emerges on 24-hour or longer recording.

Autonomic imbalance is the second pathophysiological axis ambulatory monitoring illuminates. Heart failure produces sympathetic activation and vagal withdrawal measurable as reduced beat-to-beat RR-interval variability, and the joint European and North American task force on heart rate variability formalized the time- and frequency-domain metrics now used to quantify this from ambulatory recordings [7]. Depressed heart rate variability tracks independently with mortality risk in HFrEF, a relationship established in ischemic and dilated cardiomyopathy cohorts and confirmed in the larger UK-Heart study, where a simple time-domain HRV index outperformed ejection fraction alone in stratifying death risk [8,9]. Related indices, baroreflex sensitivity, heart rate turbulence after ventricular ectopy, and deceleration capacity, extend this profiling further and were validated in post-infarction cohorts before application to heart failure [10,11,12].

3. Devices and technology for ambulatory ECG monitoring

The technological menu for ambulatory rhythm monitoring has broadened considerably, and matching device type to clinical question is now itself a diagnostic decision. Zimetbaum and Goldman's foundational framework for choosing among monitor types weighs

symptom frequency and duration against each device's recording window, from continuous short-duration Holter recording through intermittent event monitors to continuous loop recorders, and remains the starting point for selecting a strategy in HFrEF [4]. For patients with frequent arrhythmic burden or symptoms, conventional 24- to 48-hour Holter monitoring remains adequate and inexpensive, but yield falls sharply for infrequent or paroxysmal events.

Table 1: Ambulatory ECG monitoring modalities used in the diagnostic evaluation of HFrEF, by typical recording duration and principal diagnostic application [4,13,14,16].			
Device	Typical duration	Principal use in HFrEF	Key limitation
24-48h Holter monitor	1-2 days	Frequent symptoms, baseline ectopy quantification	Low yield for paroxysmal events
Adhesive patch monitor	7-14 days	Intermittent palpitations, AF screening	Single-lead signal, motion artifact
External event/loop recorder	Up to 30 days	Infrequent symptomatic events	Patient-triggered, adherence-dependent
Implantable loop recorder	Up to 3 years	Cryptogenic events, occult AF, syncope	Invasive, higher cost

Longer-duration adhesive patch monitors have partially addressed that shortfall. Barrett and colleagues compared 24-hour Holter monitoring against a 14-day continuously recording adhesive patch in the same patients and found the patch detected substantially more arrhythmic events, including atrial fibrillation, with better tolerability than a conventional Holter harness [13]. Turakhia and colleagues similarly demonstrated the diagnostic utility of a leadless, single-lead adhesive monitor, reporting that a clinically actionable arrhythmia was newly identified in a meaningful fraction of patients only because the device recorded continuously over an extended period [14]. Rosenberg and colleagues extended this technology to atrial fibrillation management, showing a noninvasive continuous patch monitor could quantify arrhythmia burden and guide rate- or rhythm-control decisions [15].

Implantable loop recorders provide months to years of continuous or triggered rhythm storage and have proven decisive where arrhythmia is suspected but infrequent. The CRYSTAL-AF investigators randomized cryptogenic-stroke patients to implantable loop recorder monitoring versus conventional follow-up and found the device detected atrial fibrillation at many times the rate of standard care by six and twelve months, echoed by the EMBRACE trial using 30-day external monitoring [16,17]. Though conducted in stroke populations, these trials established that monitoring duration is the strongest determinant of arrhythmia detection yield, a principle that now underpins ambulatory ECG strategy in heart failure. Consumer technology has entered this space too: the Apple Heart Study screened a large cohort using smartwatch irregular-pulse notifications followed by confirmatory patch monitoring, showing that even low-cost intermittent sensing can flag atrial fibrillation for ambulatory ECG follow-up [18].

4. Diagnostic yield: arrhythmia detection in HFrEF

Atrial fibrillation is among the most consequential findings ambulatory ECG monitoring uncovers in HFrEF, both because it is frequently asymptomatic and because it changes the diagnostic and prognostic picture once identified. A meta-analysis by Mamas and colleagues pooling chronic heart failure cohorts found atrial fibrillation, disproportionately detected through extended monitoring rather than presenting symptoms, was independently associated with increased mortality regardless of ejection fraction category [19]. Because paroxysmal atrial fibrillation can be entirely silent between episodes, ambulatory recording, rather than a single clinic-day ECG, has become the practical mechanism through which this diagnosis is actually made.

Premature ventricular complex burden is a second finding ambulatory monitoring is uniquely positioned to quantify, with direct diagnostic implications since a sufficiently high burden can itself cause or worsen left ventricular

dysfunction. Baman and colleagues demonstrated a graded relationship between premature ventricular complex burden on 24-hour Holter recording and ejection fraction, with a burden threshold around 24% of all beats associated with a marked rise in reduced ejection fraction attributable at least partly to the ectopy itself [20]. Yokokawa and colleagues showed that burden and cumulative duration of symptomatic complexes predicted which patients had a reversible cardiomyopathy that improved after ablation, a distinction only ambulatory monitoring can make [21]. Latchamsetty and Bogun's review underscores that ambulatory ECG quantification of ectopic burden is now a prerequisite before distinguishing primary HFrEF from an arrhythmia-mediated phenocopy [22].

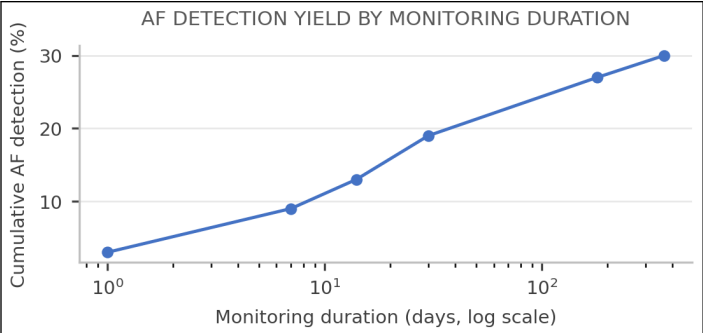


Figure 1: Cumulative atrial fibrillation detection rate by ambulatory monitoring duration in patients undergoing extended rhythm surveillance, illustrating the steep gain in diagnostic yield as recording time extends from a single 24-hour Holter study to an implantable loop recorder followed for up to twelve months [16,13].

Ventricular tachyarrhythmia detected on ambulatory recording carries the most direct prognostic weight of the findings this review addresses. Beyond the GESICA cohort, implantable-defibrillator registries examining appropriate device therapy for ventricular tachycardia or fibrillation in HFrEF have confirmed that ambulatory-detected ectopic and tachyarrhythmic burden correlates with sustained, potentially lethal arrhythmia, reinforcing guideline emphasis on ambulatory monitoring for risk stratification [23,24].

5. Autonomic and repolarization markers on ambulatory recording

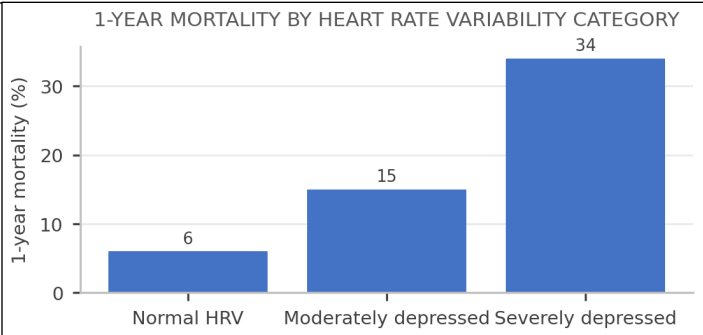


Figure 2: One-year mortality risk in chronic heart failure stratified by time-domain heart rate variability category on ambulatory ECG recording, showing markedly higher mortality among patients with severely depressed variability independent of ejection fraction [9,8].

Beyond discrete arrhythmic events, ambulatory ECG recordings carry continuous physiological signals refining both diagnosis and prognosis in HFrEF. Microvolt T-wave alternans, a beat-to-beat oscillation in T-wave morphology too subtle for visual inspection but detectable by signal-averaging algorithms, identifies patients with left ventricular dysfunction likely and unlikely to benefit from implantable defibrillator therapy, adding a repolarization-based risk axis to the rhythm information ambulatory monitoring provides [25]. QRS duration, though obtainable from a single tracing, is frequently assessed serially through ambulatory or telemetric recording, and Iuliano and colleagues showed a prolonged QRS interval independently predicted mortality in congestive heart failure, dovetailing with Baldasseroni and colleagues' finding that left bundle-branch block confers increased sudden and total mortality risk in a large outpatient cohort [26,27]. These conduction findings, captured longitudinally, have become central to identifying candidates for cardiac resynchronization therapy, validated directly in the MADIT-CRT trial, where prolonged QRS duration and ambulatory-confirmed reduced ejection fraction defined the population that benefited [28].

The autonomic indices above, heart rate variability, baroreflex sensitivity, heart rate turbulence, and deceleration capacity, together form a composite picture of sympathovagal balance a resting tracing cannot

approximate. Depressed heart rate variability has repeatedly outperformed ejection fraction alone as a mortality predictor in HFrEF, and heart rate turbulence and deceleration capacity, dependent on capturing spontaneous ectopy within a long recording, extend autonomic risk assessment into populations without severely reduced ejection fraction, broadening ambulatory monitoring's reach beyond frank arrhythmia detection [11,12].

6. Clinical integration and guideline recommendations

Contemporary heart failure guidelines from both American and European cardiology societies incorporate ambulatory ECG monitoring at multiple points along the diagnostic pathway rather than treating it as an optional adjunct. The 2022 AHA/ACC/HFSA guideline recommends ambulatory rhythm assessment for unexplained syncope, palpitations, or suspected tachyarrhythmia-mediated cardiomyopathy, and situates it as standard work-up preceding device-therapy decisions in HFrEF [3]. The 2021 ESC guideline reaches a concordant position, recommending rhythm monitoring for atrial fibrillation and ventricular arrhythmia detection and explicitly linking ambulatory-detected burden to anticoagulation, rate control, and defibrillator candidacy [29]. Both build on the earlier 2013 ACCF/AHA guideline, which first formalized ambulatory ECG in the standard evaluation of newly identified reduced ejection fraction [2].

Ambulatory monitoring also intersects with device-based therapy once HFrEF is diagnosed. The Heart Rhythm Society's consensus statement on remote interrogation of cardiovascular implantable electronic devices extends the ambulatory-monitoring principle into the postimplant period, establishing that continuous device-based surveillance improves detection of arrhythmic and hemodynamic decompensation events [30]. For patients at transient high arrhythmic risk before a permanent

device decision, the VEST trial demonstrated that a wearable cardioverter-defibrillator, continuously monitoring the ECG and able to deliver therapy for ventricular fibrillation, provides a bridge strategy built on the same continuous-monitoring logic [31]. The PRIDE natriuretic-peptide study illustrates the complementary diagnostic architecture in which biomarker testing and ambulatory ECG findings are interpreted together in suspected heart failure [32], and echocardiographic ejection fraction per the American Society of Echocardiography's chamber quantification recommendations remains the anchor against which ambulatory ECG findings are referenced [33].

Table 2: Ambulatory ECG-derived findings in HFrEF and their principal guideline-directed clinical consequence [3,29,28,30].		
Ambulatory ECG finding	Guideline context	Typical clinical consequence
Paroxysmal/silent atrial fibrillation	2021 ESC, 2022 AHA/ACC/HFSA	Anticoagulation, rate or rhythm control
Nonsustained ventricular tachycardia	2022 AHA/ACC/HFSA	Defibrillator risk stratification
High premature ventricular complex burden	2022 AHA/ACC/HFSA	Evaluation for ablation, cardiomyopathy reversibility
Prolonged QRS / LBBB on serial tracing	MADIT-CRT criteria	Cardiac resynchronization therapy candidacy
Post-implant device rhythm data	HRS remote monitoring consensus	Early detection of decompensation/arrhythmia

7. Limitations and practical considerations

Despite its expanding role, ambulatory ECG monitoring in HFrEF carries meaningful limitations. Diagnostic yield is time-dependent: a 24-hour Holter recording will miss most paroxysmal atrial fibrillation episodes that a 14-day patch or implantable loop recorder would capture, so a negative short-duration study only lowers, rather than excludes, the probability of important arrhythmia [4,13]. Signal quality is a second constraint: motion artifact, lead detachment, and obesity-related attenuation degrade interpretability, and automated arrhythmia-detection algorithms still require expert overreading to avoid

false-positive and false-negative calls [5].

Interpretive uncertainty extends to autonomic and repolarization indices as well. Heart rate variability, turbulence, and deceleration capacity require adequate sinus-rhythm duration and freedom from confounding medications such as beta-blockers, which are themselves guideline-directed HFrEF therapy and can blunt the autonomic signal being measured, complicating longitudinal comparison [7,8]. Cost also constrains use: longer-duration patch monitors and implantable recorders carry higher upfront costs than conventional Holter recording, and marginal diagnostic gain must be weighed against resource availability. Sudden cardiac death remains only partially predictable even with a full complement of ambulatory markers, as Stevenson and Stevenson's analysis of sudden-death risk stratification concluded: no single ambulatory index alone achieves sufficient sensitivity and specificity to guide defibrillator decisions without ejection fraction and clinical context [34]. Ambulatory monitoring should be understood as one component of a multimodal evaluation, not a standalone gatekeeper.

8. Conclusion

Ambulatory ECG monitoring has moved from a peripheral tool for palpitations to a central pillar of the diagnostic and risk-stratification pathway in HFrEF, driven by evidence that its most relevant arrhythmic and autonomic abnormalities, nonsustained ventricular tachycardia, silent atrial fibrillation, excessive ectopic burden, depressed heart rate variability, are largely invisible to a single resting tracing [6,19,20,9]. The proliferation of monitoring technologies, from conventional Holter recorders through patch monitors to implantable loop recorders and consumer wearables, has expanded the window over which these abnormalities are captured, and contemporary guidelines now embed ambulatory rhythm assessment across diagnosis through device-therapy candidacy [3,29]. Realizing this technology's full value will

depend on matching monitoring duration to clinical question, rigorous overreading of automated arrhythmia calls, and interpreting rhythm and autonomic data alongside ejection fraction and clinical status rather than in isolation.

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