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REVIEW

Clinical applications of heart rhythm monitoring tools in symptomatic patients and for screening in high-risk groups

Mafalda Carrington [1], Rui Providência[2,3,4], C. Anwar A. Chahal[2,5,6], Fabrizio Ricci[7,8,9], Andrew E. Epstein[5], Sabina Gallina[7], Artur Fedorowski [8,10,11], Richard Sutton [9,12], and Mohammed Y. Khanji [2,3,13]*

[1]Department of Cardiology, Hospital do Espírito Santo de Évora, Évora, Portugal; [2]Department of Cardiology, Barts Heart Centre, Barts Health NHS Trust, London, UK; [3]Department of Cardiology, Newham University Hospital, BartsHealth NHS Trust, London, UK; [4]Institute of Health Informatics Research, University College London, London, UK; [5]Cardiovascular Division, University of Pennsylvania, Philadelphia, PA, USA; [6]Department of Cardiovascular Medicine, Mayo Clinic, Rochester, MN, USA; [7]Department of Neuroscience, Imaging and Clinical Sciences, "G.d'Annunzio" University of Chieti-Pescara, 66100 Chieti, Italy; [8]Department of Cardiology, Casa di Cura Villa Serena, Città Sant'Angelo, Italy; [9]Department of Clinical Sciences, Lund University, 205 02 Malmö, Sweden; [10]Department of Cardiology, Karolinska University Hospital, Stockholm, Sweden; [11]Department of Medicine, Karolinska Institute, Stockholm, Sweden; [12]Department of Cardiology, Hammersmith Hospital Campus, Imperial College, London, UK; and [13]NIHR Biomedical Research Unit, William Harvey Research Institute, Queen Mary University of London, London, UK

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Abstract

Recent technological advances have facilitated and diversified the options available for the diagnosis of cardiac arrhythmias. Ranging from simple resting or exercise electrocardiograms to more sophisticated and expensive smartphones and implantable cardiac monitors. These tests and devices may be used for varying periods of time depending on symptom frequency. The choice of the most appropriate heart rhythm test should be guided by clinical evaluation and optimized following accurate characterization of underlying symptoms, 'red flags', risk factors, and consideration of cost-effectiveness of the different tests. This review provides evidence-based guidance for assessing suspected arrhythmia in patients who present with symptoms or in the context of screening, such as atrial fibrillation or advanced conduction disturbances following transcatheter aortic valve implantation in high-risk groups. This is intended to help clinicians choose the most appropriate diagnostic tool to facilitate the management of patients with suspected arrhythmias.

Keywords Syncope • Palpitations • Atrial fibrillation • TAVI • ECG monitoring • Holter • Implantable cardiac monitors

Introduction

Heart rhythm monitoring options have expanded beyond the classic 12-lead surface electrocardiogram (ECG), exercise ECGs and Holter monitors, now including smartphones, smartwatches and wristbands using electrodes or photoplethysmographic (PPG) sensors, extended rhythm recording using patches and wearables, external loop recorders (ELRs) and post-event recorders, handheld devices, ambulatory continuous cardiac telemetry monitoring, and implantable cardiac monitors (ICMs).[1] Prolonged out-of-hospital heart rhythm monitoring is a key component of atrial fibrillation (AF) diagnosis and assessment of its burden. They are also essential to evaluate patients who suffered events potentially related to arrhythmia, such as stroke, or who present with unexplained symptoms such as palpitations or syncope that may be caused by other suspected arrhythmias. In the latter group of patients, the assessment of both frequency and severity of symptoms is crucial for choosing the most adequate method and duration of rhythm monitoring.

In this report, we summarize the current and future clinical applications for heart rhythm testing in patients at increased arrhythmic risk or with symptoms suspected to be due to arrhythmia (*Figure 1*).

Syncope

According to the European Society of Cardiology (ESC) syncope guidelines,[2] initial work-up for syncope in the emergency department

* Corresponding author. Tel: +44(0)20 7363 8079. *E-mail address*: m.khanji@qmul.ac.uk

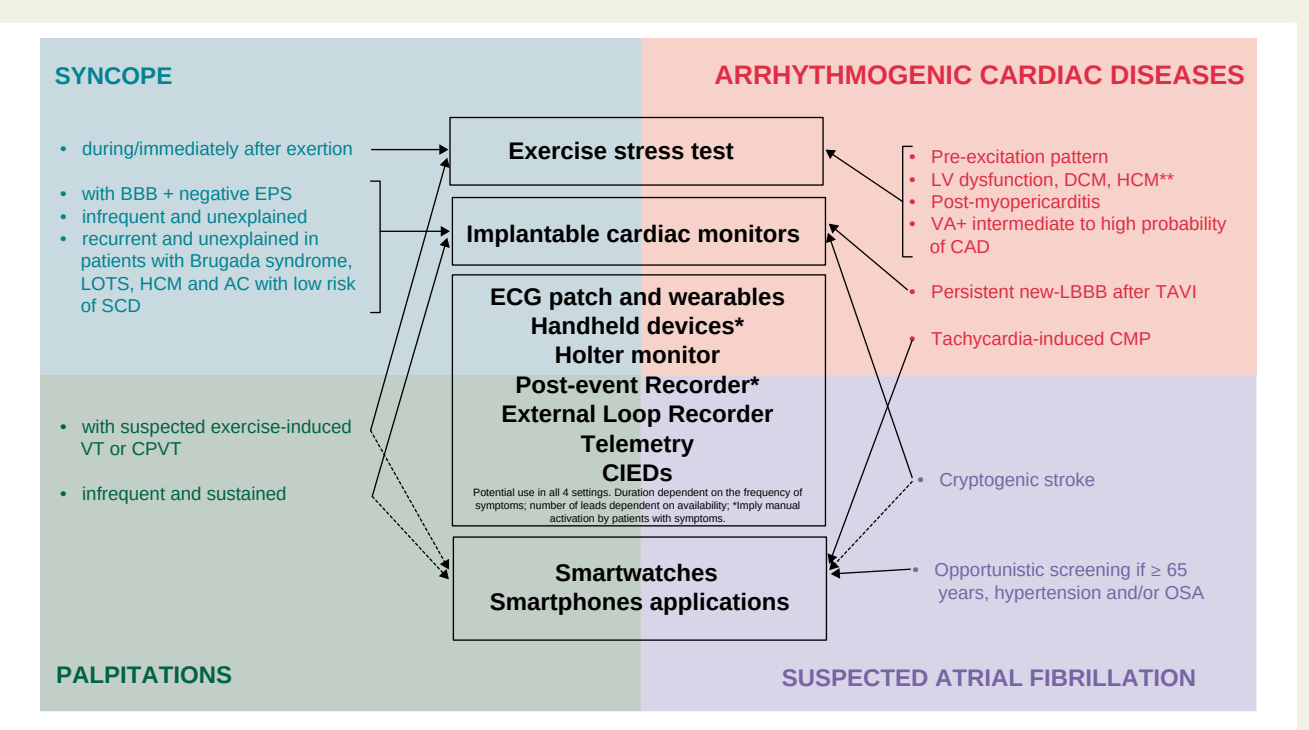

Figure 1 Indications for monitoring intermittent arrhythmias with smart electronic devices. Guideline recommendations (arrow); evidence-based indications suggested by the authors (dashed arrow). AC, arrhythmogenic cardiomyopathy; BBB, bundle branch block; CAD, coronary artery disease; CIED, cardiac implantable electronic devices; CMP, cardiomyopathy; CPVT, catecholaminergic polymorphic ventricular tachycardia; ECG, electrocardiogram; EPS, electrophysiological study; HCM, hypertrophic cardiomyopathy; LQTS, long QT syndrome; LV, left ventricle; OSA, obstructive sleep apnoea; SCD, sudden cardiac death; VA, ventricular arrhythmia. **Particularly important in athletes.

involves four steps: (i) thorough characterization of the syncopal event, (ii) past medical and family history, (iii) physical examination (including lying and standing blood pressure), and (iv) an ECG (*Figure 2*). This systematic approach allows estimation of the likelihood of cardiac syncope (*Table 1*) and initial risk stratification to guide the need for further investigations and/or treatment.

While patients with low likelihood of cardiac syncope and rare episodes do not require further evaluation, those with recurrent episodes should undergo basic cardiovascular autonomic function testing besides prolonged ECG monitoring.[2] On the other hand, individuals with high likelihood of cardiac syncope generally require in-hospital or ambulatory (short- or long-term) heart rhythm monitoring and investigation for structural heart disease and primary arrhythmic disorders. Several different arrhythmias can cause syncope, most frequently bradyarrhythmia,[3–5] and a resting ECG may raise suspicion in some cases (*Table 1*). The presence of bundle branch block (BBB) on resting ECG, for example, suggests that syncope may be secondary to paroxysmal complete atrioventricular block (AVB).[6,7] Patients with syncope and right BBB without axis deviation seem less likely to develop AVB than those with bifascicular BBB,[7,8] defined as either left BBB or right BBB combined with left anterior or posterior fascicular block. Therefore, in patients with syncope and a resting ECG with bifascicular BBB, current guidelines recommended sequential work-up with electrophysiology study (EPS), but early ICM should now be considered either as a primary strategy,[2,9] or if EPS is negative (*Class of recommendation I, Level of evidence B*).[2,10]

Additionally, 12-lead ECG may suggest a diagnosis of inherited primary arrhythmia syndromes, although the abnormalities may sometimes be transient or subtle. Electrocardiogram changes in these cases may be missed unless further heart rhythm assessment is undertaken for symptom-ECG correlation and reaching a diagnosis, especially when syncope is unexplained but *not* clinically suggestive of arrhythmia. An example is the possibly higher frequency of vasovagal syncope in patients with Brugada syndrome.[11] In this setting, although implantable cardiac device (ICD) implantation should be considered in patients with spontaneous type I ECG pattern and syncope (*Class of recommendation IIa, Level of evidence C*),[12] when a neurally mediated aetiology is suspected, these patients may be better managed by ICM to define the precise mechanism of symptoms (*Class of recommendation IIa, Level of evidence C*).[2] Similarly, patients with long QT syndrome (LQTS), hypertrophic cardiomyopathy (HCM), and arrhythmogenic ventricular cardiomyopathy also have *class IIa, level of evidence C* indication for ICMs when they experience recurrent unexplained episodes of syncope and have low risk of sudden cardiac death (SCD) according to multiparametric analysis that takes into account the other known risk factors for SCD.[2] On the other hand, in patients with primary arrhythmia syndromes who already have cardiac implantable electronic devices (CIEDs), the absence of significant arrhythmias during either in-office or remote follow-up interrogation may reinforce the diagnosis of a reflex syncope or orthostatic hypotension.[13]

There are also non-ECG related 'red flags' (*Table 1*) that suggest underlying ventricular arrhythmia (VA) or severe bradyarrhythmia,

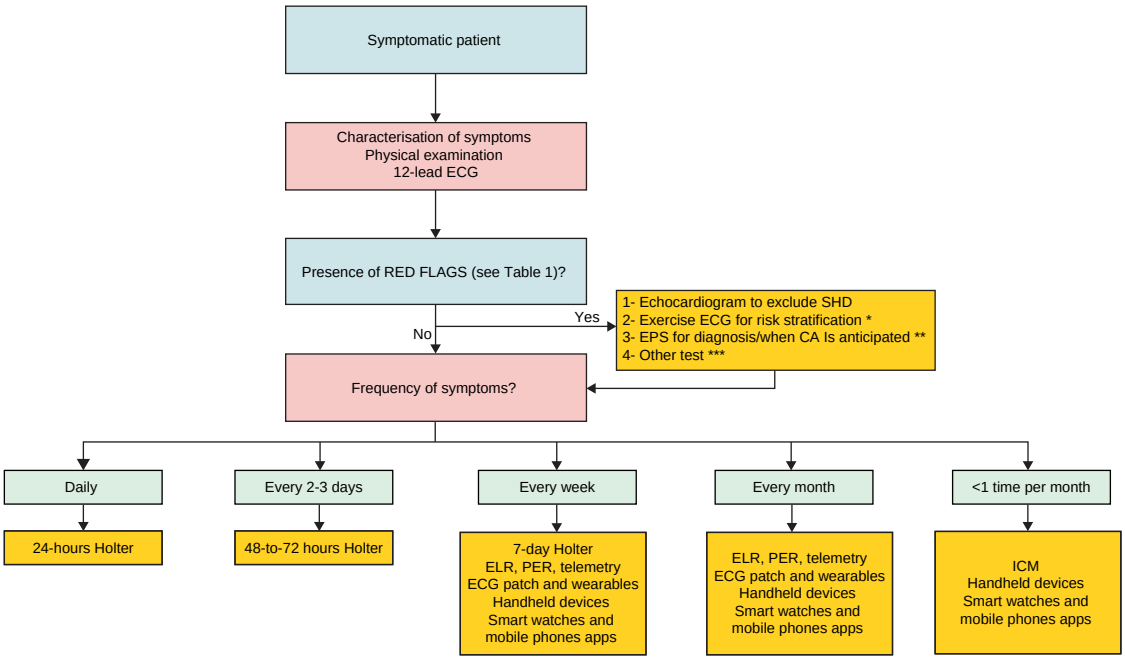

Figure 2 Guidance for symptomatic patients in clinical practice. CA, catheter ablation; ECG, electrocardiogram; ELR, external loop recorder; EPS, electrophysiology study; ICM, implantable cardiac monitor; PER, post-event recorder; SHD, structural heart disease. * If syncope during or shortly after exertion, left ventricular hypertrophy suggesting cardiomyopathy, ECG changes consistent with acute ischaemia, pre-excited QRS complexes; ** If syncope and bundle branch block in resting ECG, pre-excited QRS complexes, paroxysmal supraventricular tachycardia; *** Provocative test with ajmaline/flecainide when Brugada syndrome is suspected, cardiac magnetic resonance when arrhythmogenic ventricular cardiomyopathy is suspected.

carrying adverse prognosis and requiring close monitoring.[2] For example, syncope during exertion is concerning, it can be caused by VA or complete AVB, and exercise stress testing in this context can guide diagnosis, risk stratification, and appropriate management.[2,14]

The optimum diagnostic test allows documentation of the ECG heart rhythm during a spontaneous event, allowing symptom/rhythm correlation.[4] Symptom frequency is an important aspect of the history to determine the appropriate selection of monitoring technology (*Figure 2*): short-term ECG monitoring is indicated when symptoms occur daily (e.g. consider a 24-h Holter), every 2–3 days (e.g. 48–72-h Holter may be appropriate) or weekly (e.g. ELR or ECG patch monitors) (*Class of recommendation IIa, level of evidence B*).[1,15] Individuals with weekly to monthly symptoms can also be managed with ECG patch monitors. Alternative to standard ELR that store retrospective and prospective rhythm strips when activated by patients, the use of remote monitoring with mobile cardiac outpatient telemetry, also during a period of up to 30 days, can lead to higher diagnostic yield.[16]

Less frequent symptoms (less than once a month) in patients with suspected cardiac syncope, in whom a comprehensive evaluation is unable to demonstrate a cause, point toward the selection of an ICM (*Class of recommendation I, level of evidence A*),[14] which allows up to 5 years of recording. The use of remote monitoring during ICM follow-up is safe, increases diagnostic yield (as it decreases the risk of device memory saturation), and allows earlier diagnosis and shorter time to targeted treatment compared with conventional follow-up by in-office visits.[17,18] In the future, more widespread smartphone-based ICM remote monitoring may also allow transmissions within less than 3 min of symptom onset, although we may face difficulties in patient groups who may not be confident in using this technology.[19] Cardiac implantable electronic devices can provide similarly long monitoring during in-office or remote programmed and patient-initiated interrogations. Likewise, remote monitoring in patients with any CIED has been shown to improve survival, with a graded relationship with the level of adherence, defined as the proportion of total follow-up weeks having at least one status transmission.[20] Finally, remote monitoring benefits on early diagnosis were especially important in the context of the COVID-19 pandemic, where access to hospital consultations was limited.

However, syncope or other related episodes such as presyncope rarely occur on a daily or weekly basis. Rockx *et al.*[21] performed a cost-effectiveness analysis in patients referred for ambulatory monitoring with a diagnosis of syncope and/or presyncope, and demonstrated that ELR allows better symptom-ECG correlation compared with 48-h Holters, thus counterbalancing its upfront cost. Furthermore, as unexplained syncope episodes are even rarer (<1 per month),[22] ICMs have a higher diagnostic yield in these patients,[23] and are more cost-effective[2,24] than conventional strategies with ELR, tilt testing and an EPS study.

Brignole *et al.*[2,25] studied patients' ICM recordings and described the ISSUE (International Study of Syncope of Uncertain Etiology) classification of four electrocardiographic recordings classes obtained during syncope, see *Table 2* to which current management options according to the ESC guidelines were added. Causes of

Table 1 High risk clinical and electrocardiographic features in the assessment for cardiac arrhythmias

Red flags (adapted from ESC guidelines for the diagnosis and management of syncope[2])
Non-electrocardiographic features
• Presence of structural heart disease
• Syncope during exertion or when supine
• Sudden onset palpitations immediately followed by syncope
• Associated severe symptoms such as chest discomfort and dyspnoea
• Family history of SCD at younger age.
Resting ECG findings
Bradycardia-related findings
• Bifascicular BBB (either left or right BBB combined with left anterior or posterior fascicular block)
• Intraventricular conduction abnormalities with QRS durations ≥120 ms
• AVB, from first degree AVB with markedly prolonged PR interval to third degree
• Sinus bradycardia or slow atrial fibrillation (<50 bpm)
• Sinus pauses >3 s in awake state, in the absence of physical training
• CIED malfunctions (e.g. oversensing, loss of capture)
Tachycardia-related findings
• Non-sustained or sustained VT
• Pre-excited QRS complexes
• Paroxysmal SVT or atrial fibrillation
• Long or short QT intervals
• Early repolarisation
• Type-1 Brugada pattern
• Epsilon Waves suggestive of AC
• Left ventricular hypertrophy suggestive of underlying cardiomyopathy
• ECG changes consistent with acute ischaemia
• CIED malfunctions (e.g. pacemaker-mediated tachycardia)

AC, arrhythmogenic cardiomyopathy; AVB, atrioventricular block; BBB, bundle branch block; CIED, cardiac implantable electronic devices ECG, electrocardiogram; ESC, European Society of Cardiology; SCD, sudden cardiac death; SVT, supraventricular tachycardia; VT, ventricular tachycardia.

paroxysmal AVB (Type 1B and 1C), other than intrinsic disease of the ventricular conduction tissue (that typically causes cardiac syncope), are extrinsic vagal AVB which corresponds to reflex syncope, and extrinsic idiopathic AVB. The latter is classified as low-adenosine syncope, which is characterized by a long-standing history of recurrent syncope without prodromes, sudden-onset AVB and the absence of structural heart disease.[26] Finally, it should be kept in mind that cardiac arrhythmias, especially supraventricular tachycardia (SVT), may also trigger a vasovagal reaction.[27]

Palpitations

Patients presenting to their general practitioner with palpitations account for ∼16% of overall general medical consultations, one of the most common reasons for cardiology referral.[28] Palpitations may be defined as awareness of the heartbeat which are commonly due to sinus tachycardia or premature beats of supraventricular or ventricular origin. Many of these disturbances are physiological, psychological (in almost one-third of the cases, e.g. anxiety/stress) or due to other physical/medical conditions, such as fever or hyperthyroidism.[28] Medication or recreational drugs may affect the heart rhythm. In the context of normal heart structure and function, palpitations are unlikely to confer poor prognosis. However, in the presence of structural heart disease further assessment is required. Among cardiac causes, palpitations may result from arrhythmias and structural heart diseases such as mitral valve prolapse and severe aortic or mitral regurgitation.[29] When performing heart rhythm testing, one or more of the following five types of underlying conditions may be found: (i) premature supraventricular/ventricular complexes, (ii) AF, (iii) tachycardia, (iv) bradycardia, and (v) anomalies in CIEDs functioning. Premature supraventricular/ventricular complexes are common findings in long-term ECG recordings. However, a correlation with symptoms, evaluation of the burden of ectopic beats/h or percentage of total QRS/day and their complexity is sufficient to define the prognosis and management of these patients.[12,30] AF may cause either irregular non-rapid or tachycardia-related palpitations. Paroxysmal AF should be carefully considered in patients with ventricular pre-excitation on ECG, such as the Wolf–Parkinson–White type pattern, and irregular palpitations, a common presenting symptom harbinger of potentially life-threatening events.[31] In fact, atrioventricular re-entrant tachycardia (AVRT) can initiate pre-excited AF that can degenerate into ventricular fibrillation.[32]

Palpitations in the context of left ventricular dysfunction, dilated cardiomyopathy (DCM) or HCM, require monitoring for diagnosis and prognostic stratification with 24–48-h Holter or more prolonged monitoring, if necessary, and exercise testing for documentation of VA. These investigations may be particularly important in athletes or when the underlying clinical presentation suggests possible VA risk.[12,33] In HCM, the presence of non-sustained VT or VT on monitoring increases the HCM-SCD risk score and potential ICD indication.[12] Heart rhythm testing may also be useful in patients with arrhythmia-induced cardiomyopathy, a reversible cause of heart failure and DCM phenotype, caused by AF with the rapid ventricular response, incessant AVRT, VT, atrial tachycardias (AT), and/or very high ventricular ectopy burden.[34] The diagnosis is established by excluding other causes of heart failure, and after documenting clinical or subclinical, continuous or intermittent arrhythmias with 24-h or more prolonged ambulatory ECG monitoring.[32] In addition, there are several studies demonstrating the utility and accuracy of smartwatches and smartphones applications using PPG sensors to diagnose AF, SVT, or VT.[35–37] Therefore, the use of this kind of equipment could be suggested when patients are willing and able to buy them, and in all patients who present with these tracings, physicians should analyse them as they may be able to diagnose arrhythmias such as AF.[38]

In selected patients with a diagnosis of catecholaminergic polymorphic ventricular tachycardia (CPVT) or LQTS who remain symptomatic despite optimal therapy with beta-blockers, heart rhythm monitoring with ICMs may be useful to guide therapy, and are generally underused.[39,40] Some studies have suggested that patients with

Table 2 ISSUE classification for heart rhythm test findings and management options

ISSUE classification	Description	Final diagnosis	Management options
Type 1	Asystole (≥3 s)		*Reflex syncope mechanism by clinical history:* • Reassurance and counselling about the risk of recurrence and avoidance of triggers. Isometric counter-pressure manoeuvres and tilt training if hypotensive response, especially if *positive tilt-test.*[3] • Cardiac pacing if symptomatic asystole >3 s or asymptomatic asystole >6 s due to sinus arrest and/or AVB (patients >40 years of age).[1] *Unexplained syncope by clinical history* • Cardiac pacing if correlation between symptoms and ECG OR if Mobitz II second or three-degree AVB or prolonged asystole (>6 s).[1,3]
1A	Sinus bradycardia plus sinus arrest	Reflex syncope probable, intrinsic sinus arrest possible	
1B	Sinus bradycardia plus AVB	Reflex syncope probable, intrinsic AVB possible	
1C	Sudden AVB	Intrinsic AVB, low-adenosine syncope possible	
Type 2	Bradycardia with a decrease in heart rate of >30% or to <40 bpm for >10 s	Reflex syncope probable, intrinsic sinus arrest, or AVB possible	
Type 3	No (**3A**) or slight (**3B**) rhythm variations occur	Non-cardiac cause probable, reflex syncope possible	
Type 4	Tachycardia with an increase in heart rate of >30% or >120 bpm		
4A	Progressive sinus tachycardia	Non-cardiac cause probable, orthostatic intolerance possible if accompanied by hypotension	• Reassurance and counselling about the risk of recurrence and avoidance of triggers. Isometric counter-pressure manoeuvres and tilt training if hypotensive response.[3]
4B	Atrial fibrillation, with rapid ventricular response		• **ABC pathway**[23]: **A**nticoagulation/**A**voiding stroke, **B**etter symptom control through rate and rhythm modifying therapies, **C**omorbidities/**C**ardiovascular risk factor management
4C	Supraventricular tachycardia	AV nodal re-entrant tachycardia, AV re-entrant tachycardia, atrial flutter, or focal atrial tachycardia	• Catheter ablation is the first choice in symptomatic patients. Alternatively, drug therapy.[13]
4D	Ventricular tachycardia	Sustained or non-sustained ventricular tachycardia	• Optimization of medical therapy of the underlying disease. Drug therapy, catheter ablation, or ICD implantation may be indicated.[2,3]

AVB, atrioventricular block; NA, non-available.

LQTS tend to receive ICDs despite the absence of strong indications (documented VT or syncope).[41,12] Therefore, an ICM can provide data and avoid ICD implantation when symptom events represent benign rhythms,[39] or recommend a device when VT is diagnosed.

Finally, patients with repaired complex adult congenital heart disease such as Tetralogy of Fallot or Transposition of Great Arteries who present with suspected or clinical arrhythmia should also undergo rhythm monitoring strategies with Holter or event recorders.[42]

Currently, guidelines for the management of patients with suspected or at risk for VA only include testing with Holter, ELRs, and ICMs. However, with the increasing use of smartwatches and mobile phones that incorporate single-lead ECG applications, these along with ECG patch monitors are likely to become viable options for guidance toward diagnosis and management, as they may provide a practical and time-efficient option in the management of patients with complaints who are at the beginning of diagnostic work-up. Although it might be difficult to identify the origin of ventricular vs. atrial tachycardia with aberrancy from a single-lead ECG recording, its detection may help the clinician to evaluate patient complaints and where needed, trigger other investigations such as performance of long-term monitoring with more than one lead.

Finally, in patients who already have CIEDs, careful device interrogation may be very useful to correlate palpitations and arrhythmia. Symptoms may be caused by failure due to loss of capture, pacemaker-mediated tachycardia, pacemaker syndrome or pectoral or phrenic nerve stimulation, but they may also be caused by spontaneous arrhythmias. Cardiac implantable electronic device specific algorithms can identify and store in the device's memory atrial and ventricular intracardiac electrograms during episodes of SVT and sustained or non-sustained ventricular tachycardias. In addition, the burden of premature ventricular complexes may also be registered

by modern devices. If palpitations are frequent and of short duration, it is possible that the patient may have VT and that the ICD does not register any arrhythmia. In these cases, the number or complexes needed to detect VT may be reduced, to allow the recognition of this specific cause of palpitations. In addition, a VT below the programmed detection rate will not be automatically detected, although a patient under remote monitoring who feels palpitations may be instructed to activate an interrogation to allow treating physicians to analyse a short sample of intracardiac electrograms, and ventricular rate histograms that may lead to the diagnosis of 'slow' VT.

Suspected atrial fibrillation

Selecting the most appropriate heart rhythm monitoring strategy is particularly important in the setting of AF screening for a recurrent or *de novo* diagnosis. In patients previously undergoing cardioversion or catheter ablation, although therapy success is primarily given by symptomatic and functional improvement, monitoring AF recurrence with prolonged ambulatory ECG may be useful to assess procedural success and correlate symptoms status with rhythm.[38] On the other hand, early recognition of the first episodes of AF may help reduce symptoms and mitigate the associated risk of stroke and death, through the implementation of rhythm and rate control strategies and initiation of oral anticoagulation (OAC) treatment.[43]

When a first diagnosis of asymptomatic AF is made by using ECG monitoring tools, three different scenarios can be anticipated:

(1) subclinical AF/atrial high-rate episodes (AHREs), thus requiring AF burden (overall percentage and maximum AF episode duration) quantification for *de novo* diagnosis or follow-up after rhythm control strategies;
(2) patients who are at an increased risk of stroke and have an indication for opportunistic screening;
(3) patients who have suffered a cryptogenic stroke

The value of identifying subclinical atrial fibrillation/atrial high-rate episodes

The definition of AF has recently been revised in the 2020 ESC Guidelines.[38] Subclinical AF is defined as occurring in patients with AHRE that are detected by CIEDs, ICMs, or PPG or single-lead ECG devices, and confirmed by physician visual review of ECG or intracardiac electrograms. In these cases, confirmatory ECG tracing of ≥30 s (e.g. on 24 h-Holter monitoring) or a 12-lead ECG, physician reviewed, are necessary to diagnose clinical AF.

In a meta-analysis of 11 studies,[44] the authors concluded that subclinical AF ≥5 min is observed in 35% of unselected patients over 1–2.5 years after CIED implants, and associated with a 5.7-fold increase in clinical AF (95% CI 4.0–8.0) and a 2.4-fold increase in stroke risk (95% CI 1.8–3.3). In addition, an analysis of the ASSERT (Atrial Fibrillation Reduction Atrial Pacing Trial) data[45] demonstrated that patients with >24 h CIED-detected subclinical AF had a three-fold higher risk of subsequent stroke or systemic embolism. In fact, there may be a positive logarithmic correlation between AF duration and the adjusted hazard ratio of stroke or cardiovascular event.[46] We know from pooled data of three prospective studies,[47] that the greater the subclinical AF burden at diagnosis, the greater the progression to longer episodes, which together with a higher CHA_2DS_2-VASc score, are associated with increased stroke rates. Although evidence is lacking on optimal management of AHRE/Subclinical AF, AF guidelines suggest that closer follow-up to detect early clinical AF, regular re-assessment of AHRE/Subclinical AF burden (transition to ≥24 h), and identification and management of modifiable stroke risk factors may be necessary (*Class of recommendation I, Level of evidence B*).[38] Furthermore, the guidelines state that in high-risk males and females with CHA_2DS_2-VASc risk score ≥2 or ≥3, respectively, and episodes of duration ≥1 h, oral anticoagulants may be considered when a positive net clinical benefit can be anticipated.[38]

The subclinical AF/AHRE burden may be relevant not only for *de novo* AF diagnosis and the appropriate initiation of OAC, but also to assess AF recurrences after rhythm control strategies, either by pharmacological cardioversion or catheter ablation. Therefore, clinicians should review the tracings from CIEDs, ICMs, or other validated PPG or single-lead devices that are classified as AF by artificial intelligent algorithms, and act accordingly when a subclinical AF/AHRE episode is diagnosed, although further research to guide optimum management in such patients is required.

Opportunistic screening in high-risk populations

In older age groups, incidental ambulatory detection of AF is common. Several studies on different AF screening programmes have recently been published, the majority including patients aged >50 years, and yielding a weighted average for detection of new AF cases of 0.9% (95% CI 0.7–1.1), meaning number needed to screen of 111 subjects to detect one patient with AF.[48] In a meta-analysis assessing whether single time-point AF screening (through pulse palpation and 12-lead ECG) was efficient in the population to implement screening strategies, the incidence of previously undiagnosed AF was 1.4% in individuals ≥65 years, 67% of whom were eligible for and would likely benefit from OAC to prevent thromboembolic complications such as stroke.[49] On the other hand, Farris *et al.*[50] retrospectively reviewed 30-days clinically indicated rhythm monitoring traces of 2326 patients, which allowed a new diagnosis of AF in 3.4% of the cases, 40% of the episodes being exclusively automatically detected, corresponding to subclinical AF. In contrast, studies using longer screening from CIED or ICMs in high-risk patients (CHA_2DS_2VASc 2–4) reported a prevalence of short episodes of atrial arrhythmia in around one-third of all patients.[51]

Overall, due to silent AF prevalence, the benefit of early AF diagnosis and treatment, high event rates and the effectiveness of OAC, there is likely an indication for opportunistic AF screening in elderly populations (≥65 years) (*Class of recommendation I, Level of evidence B*),[38] in whom screening programmes were cost-effective.[52,53] In addition, a number of cardiovascular risk factors (e.g. hypertension, obesity) and comorbidities [e.g. coronary artery disease (CAD) and obstructive sleep apnoea (OSA)] are aetiological contributors to AF development. Therefore, not only is identification and management of these concomitant diseases recommended as part of AF treatment, but also opportunistic screening is indicated in hypertensive and OSA patients (*Class of recommendation I and IIa, Level of evidence B and C, respectively*).[38] Although advances in wearable technologies are likely to facilitate screening asymptomatic

AF and its consequences, randomized clinical data to confirm the true clinical benefits and optimum strategies for screening and treatment in this group are scarce and needed to guide clinical practice.

In patients ≥65 years of age, with arterial hypertension or OSA, the authors recommend opportunistic screening through pulse palpation, 12-lead ECG, and review of AF episodes automatically identified by smartwatches and smartphones applications (*Figure 1*). Although there is insufficient evidence to recommend systematic AF screening using patches, Holter monitors, or recorders, it may be considered in patients at very high stroke risk.

Atrial fibrillation monitoring with smartwatches and smartphones may raise some ethical concerns. On one hand, insurance companies may offer bonus to individuals who can prove good fitness records on their smartwatches,[54] but on the other, their insurance conditions might be prejudiced if a short run of AHRE is detected and/or a diagnosis of AF is made at a younger age, especially as precise risk criteria are not yet established. Insurance companies should provide clear information to enable individuals to make an informed decision.

Detection of atrial fibrillation after cryptogenic stroke

European Society of Cardiology Guidelines on AF recommend that in patients with ischaemic stroke or transient ischaemic attack without previously known AF,[38] continuous in-hospital ECG recording for at least the first 24-h should be performed, if possible followed by continuous 72-h monitoring. In addition, long-term non-invasive ECG monitors or ICM should be considered in selected patients {e.g. elderly, with cardiovascular risk factors or comorbidities, indices of left atrium remodelling, high C2HEST [CAD/chronic obstructive pulmonary disease (1 point each), hypertension (1 point), elderly (≥75 years, 2 points), systolic heart failure (2 points), and thyroid disease (hyperthyroidism, 1 point)] score[55]} or in those with possible embolic cryptogenic stroke (*Class of recommendation IIa, Level of evidence B*).[38] In the SURPRISE study, after cryptogenic stroke, investigation of a cardioembolic aetiology with ICM led to a diagnosis of asymptomatic paroxysmal AF in 20–30% at 3 years.[56] In the CRYSTAL-AF trial, in the 6-months following a cryptogenic stroke, ECG monitoring with ICM was six-fold superior for AF detection, compared with conventional strategies of in-hospital telemetry and 24-h Holter.[57] In the same setting of patients with cryptogenic ischaemic stroke and no prior evidence of AF, the authors of the PER DIEM randomized controlled trial (RCT) demonstrated a 3.3 higher likelihood of detecting AF with ICMs over 12 months, compared with ELR for 30 days.[58] Finally, in the STROKE-AF RCT which included patients with stroke attributed to large- to small-vessel disease aged ≥50 and at least one additional stroke risk factor, monitoring with ICM compared with usual care (ECG, telemetry, Holters, or event recorders) detected seven-fold more AF over 12 months, with low (1.8%) procedure-related localized adverse events.[59] Prolonged ECG monitoring (e.g. 72-h[60] or 10-days[61] Holter, hand-held device used intermittently twice daily for 30 days,[62] 1-month ELR,[63] or ICM[57]) increases several folds the likelihood of detecting underlying silent paroxysmal AF and tend to be superior and more cost-effective than 24 h-Holters.[64] Although the diagnostic yield of ICMs is superior to other tests for the diagnosis of AF in cryptogenic stroke, an initial strategy of up to 1-month using external cardiac monitoring allows cost-savings compared to proceeding directly to ICMs only.[65] On the other hand, although not so available, 14-day to 30-day continuous ECG monitoring (ELR) seems to be more cost-effective than repeated 24-h Holter for preventing recurrent strokes.[66] Also, in a systematic review of cost-effectiveness of extended (more than 7-day) ambulatory cardiac monitoring for AF diagnosis after cryptogenic stroke, these options were more economically attractive than conventional 24-h Holter.[64]

The authors, therefore, recommend that in patients who have had a stroke without an identified cause, after in-hospital 24–48-h telemetry, ambulatory rhythm monitoring strategies starting from 7-day ECG monitoring and with progressively increasing duration can be used to search for AF (*Figure 1*), especially in elderly, and in patients with cardiovascular risk factors or comorbidities, indices of left atrium remodelling and high C2HEST score.

Rhythm monitoring following transcatheter aortic valve implantation

Transcatheter aortic valve implantation (TAVI) may cause advanced AVB due to damage of the intrinsic conduction system by trauma, ischaemia, and oedema during or after the procedure,[67] mainly in patients in whom intrinsic mitral and aortic degenerative valvular disease and calcification already provoke some degree of AV or intraventricular block. There are predictors of need for permanent pacing after TAVI that should be considered during the preparation for the procedure, such as right BBB, left anterior fascicular block and prolonged PR interval.[14] Post-procedure cardiac telemetry during 24–48 h is essential, especially in patients with intraprocedural AVB that, if it persists, may require pacing.[14] New-onset left BBB is the commonest conduction abnormality after TAVI, although only a minority will require a permanent pacemaker.[68] In these cases, EPS or ambulatory continuous ECG monitoring for 7–30 days (or even ICMs[68]) should be considered for patients with new LBBB with QRS > 150ms or PR > 240 ms with no further prolongation during >48 h after TAVI, or it may be considered in patients with pre-existing conduction abnormality who develop prolongation of QRS or PR > 200 ms (*Class of recommendation IIa and IIb, respectively, Level of evidence C*).[14]

General points for consideration

Recently evolving technological solutions have changed the paradigm of heart rhythm testing, by enabling continuous and remote monitoring using ambulatory devices. Furthermore, these devices are contributing to a more personalized form of healthcare, not only by helping in the characterization of patient's physiology and daily activities (e.g. athletes), but also in the setting of more vulnerable patients, with underlying cardiac disease, with high risk or red flag features, who can now have their symptoms and assessment of risk performed at home.

The critical questions are whether monitoring is required and then choosing the most appropriate method that allows diagnosis without the need for multiple testing that can result in increased costs and anxiety for the patient. As previously discussed, the first step should always be an accurate patient history with characterization of clinical

symptoms and risk factors that should guide test choice. Additionally, over-testing in the absence of red flags should be avoided. In fact, heart rhythm testing may show physiological changes, such as variations in heart rate or occasional premature complexes that can cause palpitations and be stress- or caffeine-related. These findings are mostly benign, yet can exacerbate anxiety and potentially lead to over-treatment of benign heart rhythms that could be managed with lifestyle modifications.

The duration of the monitoring strategy depends mostly on the symptom frequency (*Figure 2*) or, in the case of asymptomatic AF, on the cost-effectiveness of screening strategies adopted for a given risk group. Although tests that allow longer monitoring may be more expensive, their prices may vary between countries and according to insurance policies. Furthermore, physicians must be aware of the cost-effectiveness of the different available options, as is particularly important in the investigation of the aetiology of cryptogenic strokes, in which ambulatory monitoring with duration starting from 7-days is preferable. Implantable cardiac monitors are by far the most expensive options and should be primarily used in patients in whom tests with shorter duration did not allow a diagnosis.

A few ethical issues arise while screening for AF. It is recommended that the treating physicians should inform patients about the significance and treatment implications and organize further medical evaluations to confirm the AF diagnosis in case of positive screening.[38] Although PPG devices may have greater sensitivity and specificity to detect AF and enable stroke prevention in high-risk populations, this screening mode is also associated with an important false positive rate that may raise patient anxiety leading to increased cardiology referrals, more monitoring, invasive tests, and/or over-treatment. Getting the right balance between over- and undertesting or treating may be challenging. Future studies assessing benefits, harms and cost-effectiveness should facilitate improved patient care.

Conclusions

Technological advances have made diagnosis of heart rhythm disturbances much more accessible, with a wide variety of options that allow accurate data to be collected over different periods depending on symptom frequency. The choice of the most appropriate heart rhythm monitoring tool should be guided by clinical evaluation and should be optimized through accurate characterization of symptoms, identification of red flag/risk factors, and cost-effectiveness considerations.

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