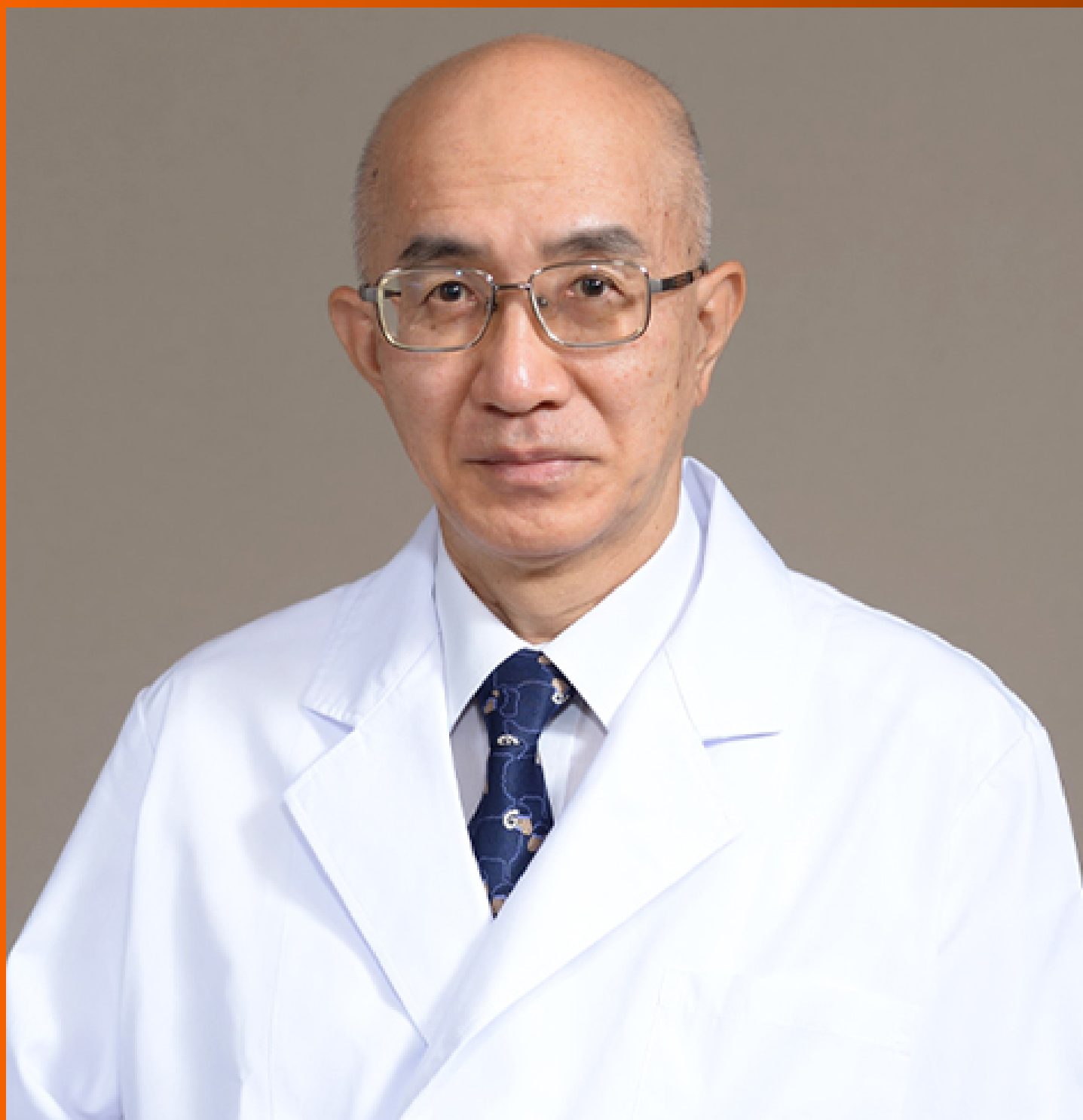


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Cardiac monitoring for patients with palpitations

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Abstract

Palpitations are one of the most common reasons for medical consultation. They tend to worry patients and can affect their quality of life. They are often a symptom associated with cardiac rhythm disorders, although there are other etiologies. For diagnosis, it is essential to be able to reliably correlate the symptoms with an electrocardiographic record allowing the identification or ruling out of a possible rhythm disorder. However, reaching a diagnosis is not always simple, given that they tend to be transitory symptoms and the patient is frequently asymptomatic at the time of assessment. In recent years, electrocardiographic monitoring systems have incorporated many technical improvements that solve several of the 24-h Holter monitor limitations. The objective of this review is to provide an update on the different monitoring methods currently available, remarking their indications and limitations, to help healthcare professionals to appropriately select and use them in the work-up of patients with palpitations.

Key Words: Palpitation; Cardiac monitoring; Electrocardiogram; Loop recorder

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Core Tip: In recent years, electrocardiographic monitoring systems have incorporated many technical improvements that solve several of the 24-h Holter monitor limitations. This review provides an update on the different electrocardiographic cardiac monitoring methods currently available, remarking their indications and limitations, to help healthcare professionals appropriately select and use them in the work-up of patients with palpitations.

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INTRODUCTION

Palpitations are one of the most common reasons for medical consultation and can occur in up to 10% of the population at some point in their lives[1-3]. They tend to worry patients and can affect their quality of life. They are a symptom that is frequently associated with cardiac rhythm disorders, although there are other etiologies[4] (Table 1). In fact, in up to half of the cases, palpitations are not due to a significant arrhythmia[2].

Having an accurate diagnosis is important to determine the prognosis, to guide treatment and to plan the patient's follow-up. In order to have a diagnosis, it is essential to be able to reliably correlate the symptoms with an electrocardiographic record allowing the identification or ruling out of a possible rhythm disorder. However, reaching a diagnosis is not always simple, given that they tend to be transitory symptoms and the patient is asymptomatic at the time of assessment[1,5].

Electrocardiographic monitoring systems are a first-line tool in assessing these patients. The introduction of the 24-h Holter monitor within 60 s was a true revolution and its use rapidly became widespread[6]. Other than diagnosing palpitations, it has also been an important tool in understanding the physiological cardiac rhythm behavior[7,8] and in the follow-up of patients at risk of cardiovascular disease[8], in syncope work-up[9-12], in risk stratification of certain patients[13-16] or in the detection of silent arrhythmias[8,17-21]. Due to its high availability and probably due to a certain degree of tradition, it is the monitoring system most commonly used by most doctors. However, it has several limitations that reduce its efficiency and diagnostic yield[2,22].

Fortunately, in recent years, in line with the overall technological development that our society has experienced, electrocardiographic monitoring systems have incorporated many technical upgrades allowing for improvement in several of the limitations presented by the 24-h Holter monitor. This evolution of electrocardiogram (ECG) recording systems has occurred in various directions. On the one hand, we have the improvement in the quality and quantity of recordings, such that, at the present time, it is possible to obtain 12-lead ECG traces of excellent quality with increased monitoring time, be it in the form of a continuous recording (which can last up to a month), or in the form of intermittent recordings which can last up to 3 years in the case of implantable recorders[8,23-25]. On the other hand, various recording and analysis algorithms have been developed, which allow for many improvements; for example, the automatic analysis of arrhythmias[18,23]. Remote data transmission systems have also been incorporated with multiple designs able to adapt to each patient's different needs[8,24,26].

Unfortunately, these new devices are still not universally incorporated into daily clinical practice, either because they are not included or reimbursed in the healthcare systems, or due to the inertia of healthcare professionals[27]. In the work-up for palpitations, it is still usual to apply a traditional strategy that is fundamentally based on the use of a 24-h Holter monitor, which has low diagnostic yield on many occasions[2,22]. This lack of yield is due to the fact that the majority of the events to be diagnosed are paroxysmal ones that occur occasionally and unexpectedly. The use of standardized diagnostic protocols with the application of new electrocardiographic monitoring devices has been shown not only to markedly improve the diagnostic yield, but also to

Table 1 Principal cardiac and noncardiac causes of palpitations

Cardiac and noncardiac causes	
Cardiac arrhythmias	Premature contractions (supraventricular or ventricular) Supraventricular tachycardia (AF, flutter, AVRNT, <i>etc.</i>) Ventricular tachycardia Severe bradyarrhythmia/ AV block Pacemaker mediated tachycardia
Structural heart disease	Severe aortic regurgitation Hypertrophic cardiomyopathy Congenital heart disease with significant shunt Mechanical prosthetic valves
Systemic causes	Thyroid dysfunction Pheochromocytoma Anaemia Fever Hypoglycaemia Arteriovenous fistula Autonomic dysfunction
Psychosomatic disorders	Anxiety Somatisation disorder
Drugs	Sympathomimetic agents (bronchodilators, antidepressants) Vasodilators (hydralazine, doxazosin) Recreational: Cocaine, alcohol, amphetamines, cannabis

AVRNT: Atrioventricular nodal re-entry tachycardia; AF: Atrial fibrillation; AV: Atrioventricular.

be clearly cost efficient[2,28-30].

However, it should also be noted that the new devices are not exempt from limitations. Some are related to patient tolerance, either due to the possibility of relative discomfort, the need to wear external devices with electrodes stuck to the skin, or because the implantable devices require a minor surgical procedure, meaning that certain patients may not accept them[8,24,27]. Also, the devices continue to record a significant number of artifacts or rhythmic abnormalities that are not pathological or significant, which inefficiently lengthen the interpretation time of the studies and can even saturate the memory of certain devices. In addition, it should be noted that for a suitable diagnosis to be made, not only is it important to have recorded a quality electrocardiographic trace; the latter must also be properly interpreted in the patient's clinical context, which requires sufficient skill on the part of the healthcare professional interpreting the trace[31].

The objective of this review is to offer an update on the different monitoring methods currently available, their indications and limitations, to help healthcare professionals appropriately select and use them in the work-up of patients with palpitations.

ELECTROCARDIOGRAPHIC CARDIAC MONITORING DEVICES

Device classification

The monitoring devices available on the market have differing characteristics. Traditionally, these devices have been classified into three or four groups [24/48-h Holter, external prospective event recorders (PERs), loop recorders (LRs)] based on a series of shared characteristics[8,27] (Table 2). However, thanks to technical develop-

Table 2 Main advantages, limitations, and indications of the most commonly used models of cardiac monitoring devices

	Advantages	Disadvantages	Main indications
24 h Holter	Continuous recording	Discomfort for the patient	Very frequent (daily) symptoms
	12 leads with good correlation with surface ECG	Artefacts	Permanent AF rate monitoring
	Low economic cost	Maximum recording of 24-48 h (low diagnostic yield)	Frequent ventricular premature beats Risk stratification of (hypertrophic) cardiomyopathies
Skin patches	Continuous recording of 7-14 d	Single use and greater economic cost	Frequent (weekly) symptoms
	Good tolerability for patients	Analysis by external companies Only one lead ¹	AF detection in cryptogenic stroke (2 wk)
External loop recorders	Loop recording (includes beginning and end of arrhythmic event)	Patient discomfort	Occasional symptoms (monthly)
	4 wk monitoring	Requires education from healthcare professional on how to correctly place the electrodes	AF detection in cryptogenic stroke (2-4 wk)
	High yield and efficiency in the assessment of palpitations		
Implantable loop recorder	Loop recording	Invasiveness and associated complications (infection, bleeding, <i>etc.</i>)	Very infrequent symptoms
	Up to 3-yr monitoring (good diagnostic yield)	Individual economic cost	AF detection in at-risk patients (cryptogenic stroke, post-ablation, <i>etc.</i>)
	Patient does not have to do anything	Single lead	Syncope
	Remote monitoring		
External event recorders/mobile devices	Easy access for the general population	Single lead ¹	Palpitations work-up
	Possibility of prolonged use (years)	Data management	Population AF screening (not validated)
	Screening for asymptomatic events (AF screening)	Patient has to be involved (not suitable for syncope work-up)	
	Remote monitoring		

¹There are devices with more leads.

AF: Atrial fibrillation; ECG: Electrocardiogram.

ments in recent years, the devices have gained in functionality and taken on new properties, making it difficult to establish a strict, closed classification. For this reason, some devices will have mixed characteristics between two groups (or will be able to be used in one or other manner according to the patient). Despite this, we should mention some of the most differentiating characteristics allowing a device and specific model to be classified (Figure 1). These characteristics must be considered when indicating the device that best suits each patient.

They may, thus, be classified according to the following.

(1) Monitoring time. There are short recording devices (24-48 h) that are useful for the examination of symptoms that occur every day or frequently; mid-range recording devices (up to 4 wk) and long recording devices (up to 3-4 years)[32]. Due to limitations of data storage, when we increase the monitoring time of the devices, they switch from continuous to intermittent recording, as will be discussed later. To achieve appropriate diagnostic yield in the work-up for palpitations, it is essential to adjust the monitoring time to the frequency of the symptoms. This is, without a doubt, one of the main characteristics when selecting a device.

(2) Recording type. This is another important characteristic to be kept in mind when selecting the most suitable test for each patient type. On the one hand, continuous recording devices such as Holter monitors make a constant ECG recording that can

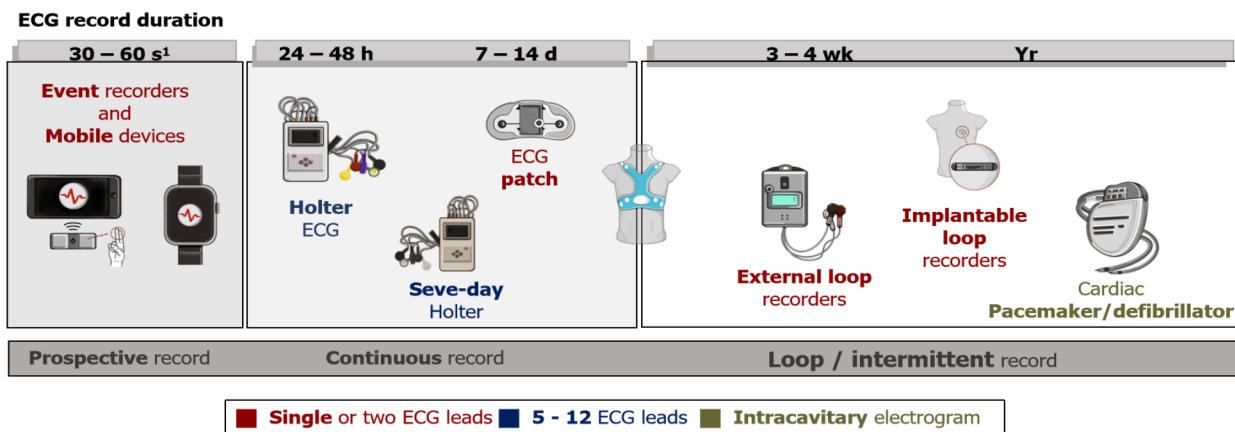


Figure 1 Main electrocardiographic monitoring devices available according to electrocardiogram recording duration and type and number of derivations. ¹While they prospectively register 30–60 s, they may be used repeatedly on a long-term basis. ECG: Electrocardiogram.

later be reviewed in its entirety. Continuous recordings avoid information loss since they do not depend on activation by the patient or on arrhythmia detection algorithms. By contrast, tests using intermittent recording are patient-activated or activate automatically according to different arrhythmia detection algorithms. There are two distinct types of device with this characteristic: Loop recorders [external LR (ELRs) or implantable LR (ILRs)] and PERs. The main difference between them is the ability of the LR to record the trace both prospectively and retrospectively, allowing us to obtain the trace from the start of the event (which may be important for the precise diagnosis of certain arrhythmias) (Figure 2). Similarly, LRs have various algorithms allowing for the automatic recording of certain asymptomatic arrhythmias, which prospective recorders do not allow for, since they are only activated by the patient in the event of symptoms (as such, they are also not useful for syncope work-up)[17,32,33]. It should be noted that there are currently certain devices available with continuous recording capacity as well as off-line analysis software with detection algorithms for arrhythmias that present the information in a similar manner to event recorders (although the healthcare professional can review the rest of the recording if this is considered important)[19,34,35].

(3) Number of leads. Recordings range from systems with just one lead to full 12-lead ECGs in the devices with the most leads. It is important to keep in mind that, the greater the number of leads, the more memory the device will use. In addition, there will be a greater number of electrodes to be applied by the patient in order for the recording to be made. As such, as a general rule, the devices allowing for long monitoring times offer a limited number of leads. However, having more than one lead is often useful. For example, on occasion, it allows for the clearing up of doubts as to whether a lead is subject to artifacts (Figure 3) or to better assess the wave morphology, which is important on certain occasions[8,36,37].

(4) Degree of invasiveness. There are implantable and external devices. ILRs require a minor surgical procedure, but once the wound has healed, patients do not usually notice them, and they allow for prolonged monitoring[17,25].

(5) Connectivity. The most up-to-date devices incorporate connectivity systems that allow for remote monitoring. Some can even be linked to smartphones, allowing for the easy sharing and sending of recordings *via* the Internet or Bluetooth[26,32,38,39]. In addition, some applications have algorithms that offer the patient an instantaneous diagnosis of their arrhythmia (although it is recommended that this is ratified by a healthcare professional)[18,40,41].

(6) Automatic algorithms. Different recording and analysis algorithms have been developed in recent years and they have been incorporated into some devices. Most of these algorithms allow for the automatic analysis of arrhythmias such as atrial fibrillation (AF), bradycardia, or asystole, but some of them also allow for the filtering out of noise to try to improve recording quality. There are differences between the algorithms that different brands incorporate into their devices. It is important to evaluate not only the algorithms that they provide, but also their sensitivity and specificity for detecting each type of arrhythmia. All of them should have type I and type II errors, but there may be significant differences depending on the device. Therefore, when selecting a monitoring device, physicians should also consider the accuracy of these algorithms.

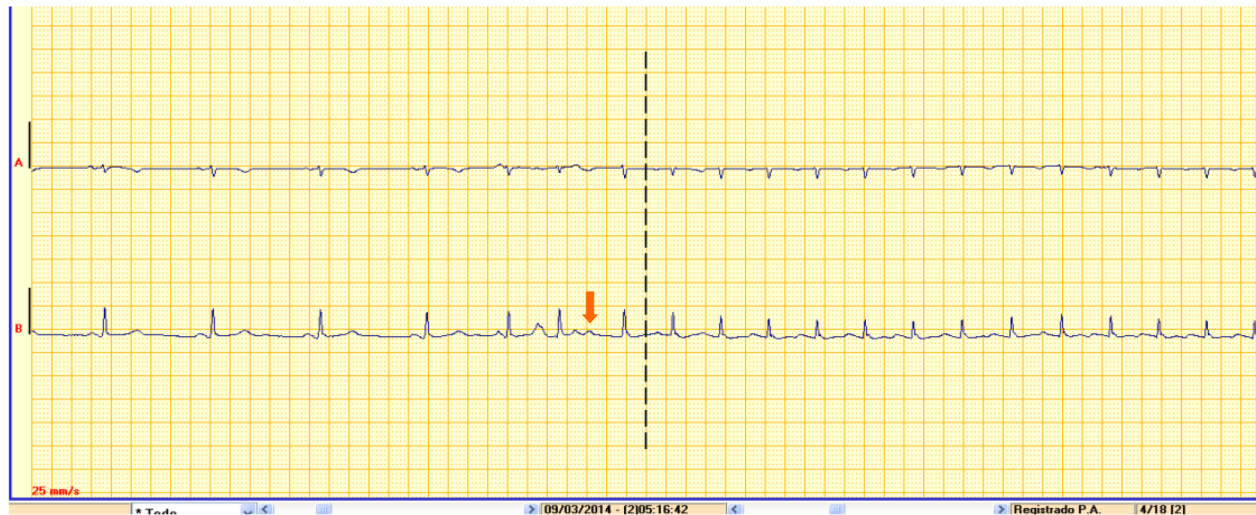


Figure 2 Example of an electrocardiogram trace obtained with an external loop recorder in a patient with palpitations. The beginning of a supraventricular tachycardia (SVT) is observed. A premature atrial beat that conducts with long PR seems to be the trigger of the SVT. This finding is highly suggestive of atrioventricular nodal re-entry tachycardia.

(7) Recording system type used. Initially, most devices used adhesives with electrodes. This is still the most common used format, although others have been developed that can record the cardiac signal, such as patches, belts or vests[8,24]. There are also devices that do not need to be in constant contact with the patient which incorporate electrodes into the recorder's own case, which are brought close to the skin when a recording is desired[42-44].

(8) Availability of other biological signals. In addition to recording the electrocardiographic trace, some devices have sensors that allow other biological signals to be monitored, such as physical activity, bodily position, oxygen saturation and even the presence of apnea[39,45,46].

Main electrocardiographic monitoring devices available

As noted above, there is currently a wide variety of monitoring devices offering a combination of characteristics, which makes it difficult to perform a strict classification. However, it is still useful to differentiate certain major groups (Figure 1 and Table 2), in the knowledge that certain models may have mixed characteristics between two groups or may be used in different ways as appropriate (*e.g.*, there are devices that can function as a 24-h Holter monitor, a continuous 3-wk Holter or a loop recorder).

Continuous Holter (24/48-h): This takes its name from the cardiologist Norman J. Holter, who developed this technology in 1961. It is currently the most common technique used in clinical practice[47]. Currently, most Holter devices consist of a lightweight recorder with a digital memory card and a series of cutaneous electrodes that obtain a continuous ECG recording. They allow for 24-48-h monitoring time in most cases, although there are devices with recording capacities of up to 7 d.

Originally, the recording was made up of only two or three leads and, still today, many tests are carried out in this way. However, as early as 1966, the first 12-lead Holter monitor was developed with a system of 10 electrodes arranged over the patient's torso. Later on, a simplified five-electrode system was developed (the EASI system) which allowed for the reconstruction of 12 leads with good clinical reliability [48]. Having 12 leads may be especially important when assessing certain arrhythmias, such as the morphology of ventricular extrasystoles or certain repolarization patterns which may only appear in one specific lead. Torso electrodes avoid possible artifacts and discomfort associated with the positioning of the electrodes on the limbs. However, it should be noted that this arrangement attenuates the amplitude of the inferior leads and generates a slight right cardiac axis deviation[48], and some recordings obtained with torso leads cannot be considered completely equivalent to standard ECG leads[8].

After completing the recording, it is transferred into software installed on a computer (and/or a server in the cloud in some of the more advanced devices), which usually allows for an initial automatic analysis identifying the QRS complexes and the

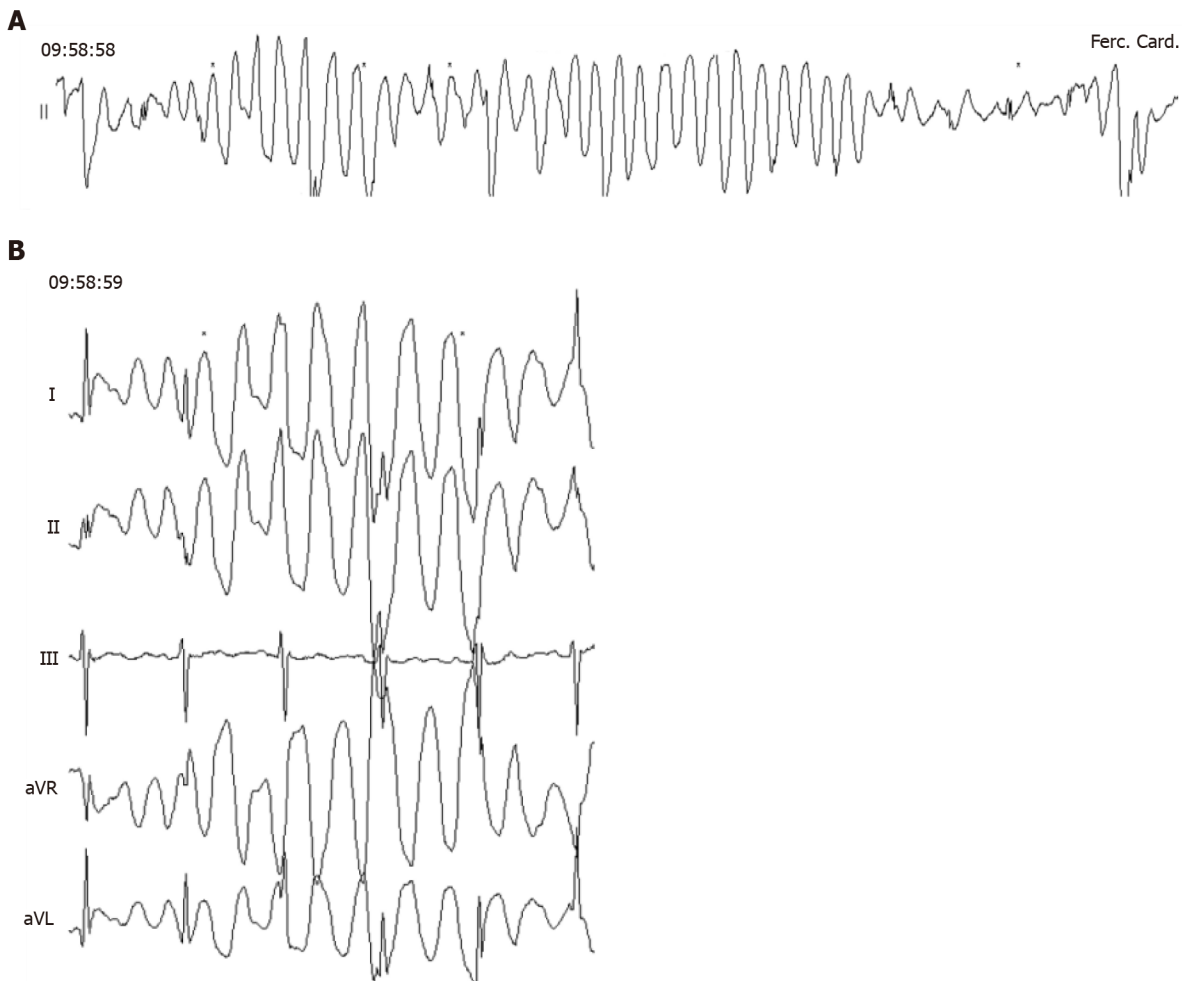


Figure 3 Example of an electrocardiogram tracing obtained with a Holter monitor with single-lead or multiple leads. A: A polymorphic trace is apparent with a single-lead record; B: After checking the other leads, the artifact can be easily identified.

R-R interval to offer values such as maximum/minimum rate, histograms of rate or ST segment analysis. Finally, the healthcare professional must review the data to rule out the presence of possible artifacts and interpret the results of the ECG taking into account the patient's symptom diary[47].

Holter monitors have demonstrated their utility in identifying arrhythmias in patients with palpitations or syncope with different efficacy values in line with the pretest probability of the population studied and the frequency of the symptoms[2,22,28]. In recent years, various case series, including our own[2,32], have shown that the global diagnostic yield of Holter monitors is limited and that, despite the fact that its cost is generally relatively low, its per-diagnosis cost is high[22,27,47]. For example, in a transversal study in usual clinical practice carried out by our group, Holter only offered a diagnostic yield of 3.5% for syncope and 16.5% for palpitations. This yield is even lower when the objective is screening for asymptomatic arrhythmias, such as AF in the context of cryptogenic stroke, where the yield can be < 1%[32].

Among other indications that have been considered, there was risk stratification in certain groups of patients, either through the detection of nonsustained arrhythmias and abnormalities of heart rate variability parameters or dispersion of the QT interval [15,49-53]. However, at the present time, few therapeutic decisions are based on Holter findings, perhaps with the exception of the presence of nonsustained ventricular tachycardia in patients with hypertrophic cardiomyopathy[15], which may be a decisive factor for the implantation of an implantable cardiac defibrillator.

In our opinion, in the work-up for palpitations at the present time, the 24/48-h Holter monitor should only be considered in patients with daily or very frequent symptoms. When this is not the case, there are other tools available that offer not only a greater diagnostic yield, but also better cost efficiency[2,39,54].

Skin patches: These systems, which were developed over the past decade, enjoy a certain degree of popularity in some countries. However, in others, such as Spain, their

use remains marginal. They consist of patches of different materials, which adhere to the skin and contain electrodes to obtain one (the most common) or two ECG leads for 7–14 d' monitoring. The device itself acquires, amplifies and filters the ECG signal, which is then telematically transmitted for analysis (usually through an external company)[8,24,55].

There are different patch models with different recording characteristics. In some cases, they are similar to a Holter monitor and in others to an ELR. For example, the ZioPatch creates a continuous ECG recording with a single lead that is interpreted *via* an analysis platform. It also has a symptom button on the patch itself[56,57]. Another different example is the NUVANT-Piix. It also has only one lead, but it does not perform a continuous recording; rather, it only records the traces identified as arrhythmias or when the patient experiences symptoms and activates the device with a special magnet[58].

There are studies comparing the efficacy of these new patches with traditional Holter monitors (Table 3), showing good tolerability on the part of patients and a greater diagnostic yield, particularly for the purposes of identifying paroxysmal AF [56,59]. However, these devices have a higher cost and are usually single use[8,56].

In this section, we can also include the so-called “textrodes”, which are electrodes included in garments[34]. These devices are currently in a more experimental phase. One of the main problems they entail is the quantity of artifacts due to movement of the fabric. In this regard, studies are being carried out to select the best material and electrode positioning within the fabric[60,61].

Prospective external event recorders (without loop memory) and mobile devices:

These tend to be small devices with a couple of electrodes incorporated into them, which allow, when activated by the patient, for a real-time recording of 30–60 s of a single ECG lead[8,24,41,44]. These devices allow for the recording of episodes of palpitations that are sufficiently long for the patient to have time to apply the recorder. However, they have the limitation of not allowing for the recording of the start of the episodes, which is frequently important for diagnosis when it comes to interpreting the mechanism of arrhythmias[32,39] (Figure 2). Similarly, their use is not appropriate for syncope work-up, because if the patient applies the device having recovered from the syncopal episode, in most cases, the possible cause of the syncope will have disappeared[10].

In recent years, these devices have become popular, since they are small devices that do not have to be constantly in contact with the patient and allow for prolonged use (even years, since the batteries can be recharged and they only record when activated), as well as having a relatively low cost. There are currently numerous models from different brands, with various designs. In addition, some of these models link to or are even included as tools belonging to smartphones or smartwatches (such as the Apple Watch), which allows for greater and easier access for the general public[24,40]. Indeed, a significant number of users, especially those of smartwatches, have no medical indication, which may also be controversial[62].

In most models, the recordings are stored in the device itself or in a linked mobile phone. Many incorporate their own algorithms which allow for the identification of certain types of arrhythmia (especially AF), and offer the option of being sent to health centers for interpretation[40,41,44].

Due to their simple use and accessibility, these applications' utility for other indications such as population AF screening (most useful in patients aged > 65 years) [63,64] or also for the detection of cardiac ischemia has been analyzed[65–67], which could facilitate diagnosis in patients who live far away from health centers. New mobile devices are also being developed (they are not yet on the market) which obtain an ECG signal from the patient on an involuntary basis while the devices are being used as normal, which would allow for the intermittent detection of asymptomatic cardiac rhythm disorders[44,63,64,68].

LRs: These allow for more prolonged monitoring, since they do not store a continuous recording[2,49,69]. Even though they continuously monitor the ECG, the device only stores it in its memory for a few minutes before subsequently overwriting it with a newer recording (initially it was an endless circular tape, although the devices are now digital). Only when the device is activated (either *via* manual activation or an automatic arrhythmia detection algorithm), it records on another part of the memory (where it will not be deleted and can be reviewed) the recording from a few minutes before the start of the event until its end. In this way, since several minutes before activation are stored in the device memory, the likelihood of recording the trace at the time of the syncope episode (if it is activated for syncope), or the start of the episode of

Table 3 Summary of relevant studies on diagnostic yield for palpitations according to the different types of devices

Ref.	No. of patients	Study design	Study population	Duration of monitoring	Diagnostic yield	Other findings
Holter 24 h						
Sulfi <i>et al</i> [22], 2008	2688	Retrospective cohort	Palpitations and basal sinus rhythm	24 h	16%	Even less diagnostic yield in patients aged < 50 yr
Paudel <i>et al</i> [103], 2013	335	Single-center prospective cohort	Palpitations	24 h	75%	40% of patients with ventricular ectopy considered as diagnostic finding (possible selection bias)
ECG patches						
Barrett <i>et al</i> [59], 2014	146	Prospective cohort comparing Patch vs 24 h Holter	Palpitations	15 d	60% more diagnostics than 24 h Holter	Over 90% of patients were comfortable with it. Best diagnostic yield during first week
Event recorders						
Narasimha <i>et al</i> [104], 2018	38	Prospective cohort comparing Kardia Mobile vs ELR (simultaneously)	Palpitations (less often than daily but more than monthly)	14–30 d	89.5% vs 68% in ELR group	Better compliance with Kardia Mobile
Hall <i>et al</i> [63], 2020	11 studies (> 20000 patients)	Systematic review	AF screening in general population	Heterogeneous	Up to 36% (depending of population's AF burden)	More diagnostic yield in people aged > 65 yr. Approximately 4% of uninterruptable registries
ELR						
Locati <i>et al</i> [54], 2016	392 (282 with palpitations)	Prospective cohort	> 2 episodes in last year	4 wk	71.6%	Early recorder use increase diagnostic yield. Diagnostic yield for syncope: 24.5%
Francisco-Pascual <i>et al</i> [2], 2019	149 (91 in ELR group)	Prospective ELR cohort compared with historical Holter cohort	> 2 episodes in last year	21 d	86.8%	Holter diagnostic yield: 20.7%. ELR reduce the cost per diagnosis
ILR						
Giada <i>et al</i> [29], 2007	50 (26 in ILR group)	Prospective cohort comparing ILR with conventional strategy	1 episode per month or less (longer than 1 min)	321 d (mean)	73%	Mean time to diagnosis: 279 d. Lower cost per diagnosis in ILR group
Padmanabhan <i>et al</i> [83], 2019	312 (51 with palpitations)	Prospective cohort of consecutive patients with an ILR implanted	Any indication form monitoring (16.3% due to palpitations)	579 d (mean)	64.7%	38.7% useful in ruling out an arrhythmic cause for symptoms (all indications). 12% AF.

ELR: External loop recorders; AF: Atrial fibrillation; ILR: Implantable loop recorders.

palpitations, is high[2,54,70,71].

At the present time, most LR's can record symptomatic arrhythmias after activation by the patient, usually in the context of symptoms, or silent arrhythmias on an automatic basis[25]. Within this category, we differentiated between external and implantable devices.

(1) ELRs: External event recorders are characterized by a loop memory, which uses cutaneous electrodes to record, be this in the form of independent electrodes or those integrated into a t-shirt. The patients themselves position the electrodes daily[8,25].

Due to the characteristics of these devices, these systems tend to be worn by patients for no more than a few weeks (usually 3–4 wk, although there are reports of more prolonged periods). They are useful for the investigation of symptoms that occur every 2 or 3 wk. It should be noted that palpitations usually occur more frequently than syncopal episodes, hence the diagnostic yield for palpitations is approximately 80% [2], whereas in cases where it is indicated for syncope, it is no greater than 10% [54,72–74] (Table 3).

The quality of the recordings tends to be good, although there may be a not insignificant number of recordings corresponding to an artifact. Another limitation may be patient adherence to the daily positioning of the electrodes, even though this is

generally good, as well as the possibility that the patient may develop an allergy to the electrodes, even though this is rare[54,72].

In the investigation of palpitations, in addition to a high diagnostic yield, it allows for improved cost efficiency in the work-up of these patients[2,73]. A recent study by our group[2] compared the use of ELRs with a conventional Holter strategy in patients with more than two episodes of palpitations *per* year. We were able to demonstrate that investigation in the form of a diagnostic protocol, including that the use of an ELR, had a notably superior diagnostic yield (86% *vs* 21%) and offered a significant reduction in per-diagnosis cost (€375.13 in the ELR group and €5184.75 in the control group ($P < 0.001$). The cost-effectiveness study revealed that the systematic use of ELRs resulted in a cost reduction of €11.30 for each percentage point of increase in diagnostic yield.

Another usual clinical application of these devices is in patients with stroke of unknown etiology. It has been demonstrated that the use of these devices in patients with cryptogenic stroke, compared with the usual strategy of conventional follow-up and 24- or 48-h Holter monitoring, increases the detection rate of silent AF, allowing oral anticoagulation to be started in a greater proportion of patients and at an earlier stage[19,49,75-77].

(2) ILRs: These are small devices that are implanted subcutaneously, usually in the left parasternal region[8,25]. These devices allow for a more prolonged continuous monitoring of up to 3 to 4 years. They offer a single-lead ECG recording. The patient can activate the device when symptoms are experienced using a small remote control or through a smartphone application. Like the external devices, they use automatic arrhythmia detection algorithms[18,33]. The devices available on the market also offer a platform for remote monitoring of the events recorded, sometimes also with data transmission to the patient's mobile[20,26,32].

They have the disadvantage of being minimally invasive, since the latest models have been made significantly smaller. They require a brief surgical procedure for their implantation. There are complications in a small percentage of patients requiring the device to be withdrawn, ranging from local infection/hematoma to intolerance[78,79]. Another limitation is the price of the device, which is significantly greater than that of ELRs[25,29].

In recent years, there has been abundant literature on the diagnostic yield of implantable recording devices. The greatest experience with this kind of device concerns patients with syncope of unknown etiology[10-12], given the long monitoring time that they offer, with diagnostic yield figures around 35% [9,18,30,70]. There are also numerous papers analyzing the role of ILRs in patients with stroke of unknown etiology, and, as with ELRs, it has been shown that the strategy of implanting an ILR leads to a greater and earlier diagnosis rate than following a conventional strategy[49, 80]. They are also used in risk stratification and follow-up of certain patients[13-16,81, 82].

In the field of palpitations, their use has been more limited due to their cost and the availability of noninvasive and cheaper alternatives[83]. The recurrent unexplained palpitations study[29] compared an ILR with a conventional strategy, confirming a notably superior diagnostic yield in the ILR group (73% *vs* 21%). Despite the higher initial cost, the cost *per* diagnosis in the ILR group was lower than in the conventional strategy group (€3056 ± 363 *vs* €6768 ± 6672, $P = 0.012$). However, with the appearance on the market of new ELR devices with good diagnostic yield figures, the use of ILRs is reserved for select cases.

Outpatient telemetry monitoring: These are external monitoring devices similar to Holter monitors or cutaneous patches, but which send a continuous recording *via* telemetry to a central site where the ECG trace can be reviewed in real-time in the event of the onset of symptoms[38,58]. Subsequently, the information can be sent to medical centers with a greater or lesser degree of urgency[8]. Like the skin patches, their use varies according to the region and they are not available in all countries. The most common indication tends to be to monitor for the presence of AF after ablation procedures or to monitor the presence of significant arrhythmias following cardiac surgery or transcatheter aortic valve implantation[8]. Some records have demonstrated the greater efficacy and efficiency of this method compared with conventional Holter monitors[84].

Intracardiac devices: Despite intracardiac devices (pacemakers, defibrillators or resynchronizers) not being indicated for the purpose of monitoring, it should be mentioned that they are also useful for the work-up of patients with palpitations in cases where patients have one of these devices for another indication, since they offer a recording of the intracavitary electrogram during the episode. Many devices have

algorithms that automatically record these events allowing for their subsequent analysis. As such, it is not an ECG recording, but in the case of dual chamber devices, information can be obtained regarding the start of the event and the AV synchrony during tachycardia[85-87].

WORK-UP OF PATIENTS WITH PALPITATIONS

The aim of this section is to provide some clues to help physicians manage patients with palpitations, focusing on the proper use of electrocardiographic monitoring systems. However, it is mandatory to make a brief reference to other important aspects for the evaluation and management of these patients.

Clinical evaluation and risk stratification

The sensation of palpitations is a nonspecific symptom with multiple causes, which are not only cardiological. As such, it is essential to take an appropriate medical history to guide us towards a given suspected diagnosis, allowing us to choose the most suitable tests.

It is important to ask about the patient's medical history (systemic diseases, cardiological history, drug-abuse history, family history of sudden death, *etc.*). Similarly, it is relevant to ask about the characteristics of the palpitations: Are they sustained over time or not, or are they regular (sinus tachycardia, paroxysmal supraventricular tachycardia) or irregular (AF). The triggers (onset at rest or during physical exertion or with stressors) and the presence of certain accompanying characteristics (such as autonomic symptoms, syncope or anginal chest pain) are helpful in identifying at-risk patients requiring admission or more urgent monitoring[1,3].

The physical examination and other easily accessed complementary tests such as electrocardiography can offer specific data but with low sensitivity[1,88]. For example, the presence of a normal ECG does not exclude the presence of causes or arrhythmias, but any pathological findings do greatly increase the likelihood that the cause of the palpitations was cardiological. In up to 27% of patients, the ECG is the key to the diagnosis[88].

Thus, the initial assessment usually includes a detailed clinical history, a focused physical examination, a baseline ECG and usually also a general blood test including thyroid hormones. It is not uncommon in cardiology consultations to also systematically request an echocardiogram to rule out structural heart disease, although this may not be necessary in patients with no other risk factors for heart disease with symptoms highly suggestive of a nonrhythmic origin.

Selection of monitoring type

A key point after risk stratification is appropriately selecting the type of monitoring to be used among all the available devices, in order to achieve optimized diagnostic yield and efficiency in the patient in question.

In the field of palpitations, it is essential to correlate the patient's symptoms with the electrocardiographic recordings to reach an objective diagnosis[2,6]. This point is worthy of special mention, because it is not uncommon for patients with palpitations to experience different sensations that may correspond to different disorders. For example, it is not unusual for patients to have a sensation of a single palpitation lasting a few seconds almost every day, but to also report occasional episodes of sustained rapid palpitations that start and end suddenly. If, using a Holter monitor, we record an atrial extrasystole and relate this to the single palpitation sensation, we cannot rule out the possibility that these extrasystoles trigger episodes of paroxysmal supraventricular tachycardia (which would explain the second, less frequent, symptom). It would be an error to attribute the entirety of the patient's clinical presentation to the extrasystole, and we should select a monitoring method allowing us to record the less frequent symptom (which is the one suggestive of greater clinical importance). As such, it is essential to take a meticulous history of the symptoms experienced by the patient during monitoring before establishing a certain diagnosis[1, 29].

As noted in the previous section, we currently have a wide range of devices at our disposal with significant differentiating characteristics. Various aspects must be considered. The first, and probably the most important, is the frequency with which the symptoms are experienced. The monitoring time must be in line with this frequency. As such, ideally, a 24-h Holter monitor should only be indicated in patients

with frequent and almost daily symptoms[22,48]. If the symptoms are monthly or bimonthly, ELRs have shown excellent diagnostic cost-effectiveness and have certain advantages over other devices[2,54], such as obtaining information regarding the start of the episode. In the event of more infrequent symptoms, at present, external PER are probably the device of choice.

Another important factor is device availability. Many of the new devices are not yet offered as a usual diagnostic tool at healthcare centers or are not covered by insurers. If the patient cannot fund the device, we must choose from among those we have available.

Patient comfort, cost, the accuracy of the automatic algorithms, the possibility of carrying out telemetry monitoring, and the need or otherwise to be able to record the start of the episode are other factors that may influence our decision[8].

Finally, it should be pointed out that, within a specific group of devices, it is important to ensure that the model selected has suitable technical characteristics providing a good quality recording.

Electrophysiological study

Although it is not the reason for this review, it should be mentioned that electrophysiological study (EPS) is an important diagnostic tool in managing patients with palpitations[1,89,90]. In addition to allowing for a precise diagnosis of certain arrhythmias (such as paroxysmal supraventricular tachycardias), it is possible to treat the arrhythmia with ablation during the procedure in those cases where it is indicated [91-93]. It also allows to evaluate other causes of syncope if present[9,10,94,95], and performing risk stratification in patients with structural heart disease[14,71]. Since it is an invasive test, it tends to be considered at the end of the diagnostic process, either in patients with a high probability of significant arrhythmia when the monitoring methods have not allowed for it to be documented, or in patients where, after documenting the clinical arrhythmia, ablation treatment is planned. Nonetheless, it may be indicated at an early stage in patients with recurrent palpitations whose clinical characteristics are highly suggestive of paroxysmal supraventricular tachycardia and who, as such, can benefit from ablation[1,88,89,96].

The diagnostic yield of electrophysiology study is greater in patients with structural heart disease and in those with clinical symptoms highly suggestive of paroxysmal supraventricular tachycardia. For example, in a study carried out by Valles *et al*[90] on patients with sustained palpitations that did not appear on monitoring, the diagnostic yield was 50%. Other papers have reported yields between 40% and 66%[1,89].

In any case, in our opinion, prescribing an electrophysiology study should not preclude the need for electrocardiographic monitoring during the waiting time, be it *via* telemetry monitoring systems if the patient is admitted, or with an external device if not.

Other tests

Exercise-stress testing can be useful and should be considered from the outset when patients report palpitations on exertion[1,97]. Magnetic resonance imaging, coronary computed tomography, specific hormonal studies, *etc.* should be tailored to the patient in line with clinical suspicion and will be necessary in a minority of cases.

Palpitations management work-up summary

Figure 4 summarizes the proposed general algorithm for the management of patients with palpitations of unknown etiology. This algorithm offers an overview of the issue, although it can and should be adapted in specific cases and according to the availability of tests at the center.

The first step in all patients is to perform an initial clinical assessment and stratify the risk (as stated in section *Clinical evaluation and risk stratification*). In those patients with high-risk criteria and/or priority for EPS, it is necessary to prioritize tests and indicate the study in most cases. During the waiting period, a monitoring system should be maintained (telemetry if the patient is admitted or an ELR if it is an outpatient), because this may provide the diagnosis faster and obtain relevant information for the rest of the work-up.

In cases without risk factors (which form the majority of cases), and without a diagnosis, it is necessary to select a monitoring system, following the indications in section *Selection of monitoring type*.

Patients without heart disease and with sporadic symptoms not suggestive of an arrhythmic origin may not require further cardiological tests. However, it is not uncommon for the clinical symptoms to continue to generate a high degree of anxiety,

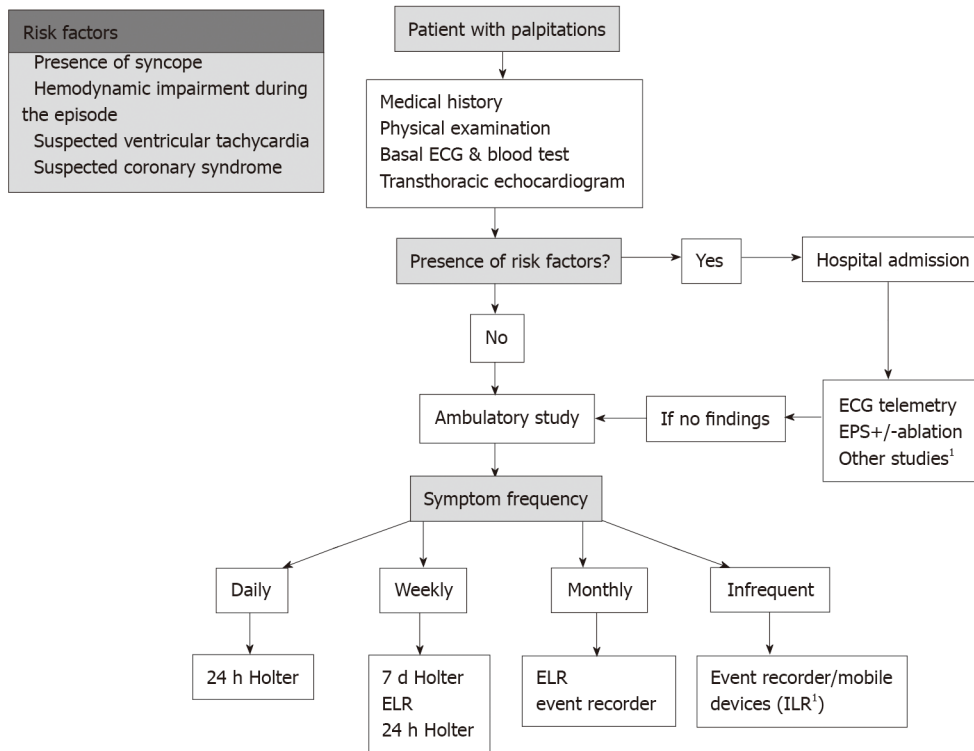


Figure 4 Proposed general algorithm for the management of patients with palpitations of unknown etiology. ¹Consider only in selected patients. ELR: External loop recorder; ILR: Implantable loop recorder; ECG: Electrocardiogram.

hence in some cases we may consider monitoring to ensure there are no arrhythmias, to reassure the patient and to avoid other futile investigations and consultations.

FUTURE PERSPECTIVE

Technological evolution shows no signs of slowing down and it is likely that monitoring devices will continue to be developed at high speed. We expect more widespread use of wearable devices, which incorporate sensors for other vital signs, to open the doors to other indications for monitoring. With regard to electrocardiographic monitoring specifically, we expect further work to be done to improve the current limitations. On the one hand, developing reliable devices that allow for quality external, comfortable, and long-lasting monitoring. On the other hand, the current recorders continue to produce a high number of artifacts and nonsignificant disorders, hence the development of software with algorithms to improve this area will be of clinical utility. The incorporation of artificial intelligence technology allowing for the prediction of future events is another of the most pioneering lines of research[98-102].

Without a doubt, technological development will help us improve the diagnosis and follow-up of patients with palpitations and other cardiac conditions. However, we must be cautious about the increasingly frequent nonmedical use of these devices. We healthcare professionals are faced with the challenge of how to manage, interpret and integrate into the healthcare system all the information that these new devices are providing.

CONCLUSION

Electrocardiographic cardiac monitoring devices are a useful diagnostic tool in confirming or excluding arrhythmias in patients with palpitations. In recent years, electrocardiographic monitoring systems have incorporated many technical improvements and many new devices are now available on the market. To achieve the best diagnostic yield and efficiency, a key point is to properly select the type of monitoring to be used among all available devices. This review provides an update on the different monitoring methods currently available, highlighting their indications

and limitations, to help healthcare professionals to appropriately select and use them in the work-up of patients with palpitations.

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