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Remote Monitoring of Cardiac Implantable Electronic Devices: What is the Evidence?

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Abstract

Purpose of Review This review offers an overview of the evidence in diagnostic and therapeutic applications of remote monitoring implantable devices.

Recent Findings Remote monitoring of cardiac implantable devices has become more and more popular in recent years as healthcare is moving towards a more patient centralized system. For heart failure patients with an ICD or pacemaker, there is controversial evidence regarding improvements in the clinical outcome, e.g., reduction of hospitalization rates or overall mortality. New developments as hemodynamic remote monitoring via measurement of the pulmonary artery pressure are promising technical achievements showing encouraging results. In cardiac remote monitoring of syncope and arrhythmias, implantable loop recorder plays an important role in diagnostic algorithms.

Summary Although there is controversial evidence according to remote monitoring of implantable devices, its use is rapidly expanding, giving healthcare providers the opportunity to react promptly to worsening of their patients. Adequate evaluation of the data created by remote monitoring systems remains an unsolved challenge of contemporary healthcare services.

Keywords Remote cardiac monitoring · Cardiac implantable devices · Heart failure · Hemodynamic remote monitoring · Implantable loop recorders

Abbreviations

RM	Remote monitoring
CIED	Cardiac implantable electronic device
ICD	Implantable cardiac defibrillator
PM	Pacemaker
CRT	Cardiac resynchronization therapy
IO	In-office
CHF	Congestive heart failure
HRV	Heart rate variability
CV	Cardiovascular
RCT	Randomized controlled trial
IIM	Intrathoracic impedance monitoring
AAR	Atrial arrhythmias
AF	Atrial fibrillation
WD	Wearable devices
PAP	Pulmonal arterial pressure
ILR	Implantable loop recorder

Introduction

In recent years, especially during the ongoing coronavirus pandemic, remote monitoring (RM) for cardiac implantable electronic devices (CIEDs) has become increasingly popular and accepted. Its use has spread more and more, improving healthcare accessibility, becoming a key factor towards an upcoming more personalized therapy.

For active cardiac devices such as defibrillators (ICDs), pacemakers (PMs), and cardiac resynchronization therapy (CRT), RM is an accessory function that can be activated if necessary. Other devices, such as implantable loop recorders and CardioMEMS™, are set up for the sole purpose of monitoring.

The data obtained from the monitoring system is sent in real time on a database to which the healthcare staff has online access. CIEDs have the ability to send data automatically in cases of device malfunction or detection of

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life-threatening arrhythmias. Data transmission can also be actively initiated by the patient in case of disturbances or suspicion of worsening of the clinical situation [1–3].

This allows avoiding some conventional in-office (IO) follow-up, a condition which is especially advantageous for patients who live far from the referral hospital, as often happens in countries with low distribution of medical centers due to centralization[3].

One of the main collectives for which remote monitoring systems are intended is patients with congestive heart failure (CHF), in which the early recognition of a worsening of cardiac performance can allow rapid treatment and thus avoid hospitalization or even death [1–4].

Although, thanks to advances in medicine, the rate of CHF patients is decreasing, the absolute number of heart failure patients is continuously increasing as the global population and life expectancy. For example, in the UK between 2002 and 2014, CHF incidence decreased by 7%. However, the estimated absolute number of individuals with newly diagnosed CHF increased by 12% [5]. In the USA, the prevalence of CHF will increase 46% from 2012 to 2030, resulting in more than 8 million adult people with CHF [6].

Thus, an ever-wider diffusion of remote monitoring systems is expected in the coming years [7].

The purpose of this article is to give an overview of the most relevant implantable cardiac devices offering RM and the evaluation of their clinical evidence.

Cardiac Monitoring via Pacemakers, Implantable Cardioverter Defibrillators, and Devices for Cardiac Resynchronization Therapy

Currently available hardware devices provided by the different manufacturers are very similar in terms of handling and connectivity (Fig. 1).

Detection of Device-Related Complications

RM in CIEDs is well established in early detection of device-related technical problems and inappropriate shocks [8–12]. In the TRUST trial, ICD patients were randomized to RM with daily transmissions or to conventional care with IO visit only. Lead and generator problems were detected significantly earlier in the RM group compared to the conventional care group (median of 1 vs. 5 days, respectively; $p = 0.05$) [13]. Furthermore, RM has been demonstrated to be safe and useful in reducing of in-hospital device evaluations [8]. In the study of Watanabe et al., 1274 consecutive patients implanted with a PM have been randomized to RM only or IO follow-up. After 2 years, RM only did not increase the occurrence of death, stroke, or cardiovascular events requiring surgery (10.9% vs. 11.8%, respectively, $p < 0.01$ for non-inferiority), suggesting that RM is not only safe but can be a potential tool to reduce resource consumption as well [14].

Recently, most of the manufacturers of implantable cardiac devices faced problems with lithium plating which randomly can cause rapid battery depletion. Here, activating RM was strictly recommended by the manufacturers and became a beneficial and irreplaceable instrument for both patient and healthcare professional helping to detect affected devices as early as possible [15–17].

Detection of Heart Failure Decompensation Using CIEDs

Despite improved outcomes of patients with CHF due to new treatments, morbidity, mortality, and hospitalization rates remain still high [18].

As the 30-day all-cause readmission rate approaches up to 20%, the 10-year mortality reaches almost 100% [19, 20]. Furthermore, hospitalizations account for approximately 70% of the global costs [21].

While optimal medical therapy impacts the natural history of the disease, active cardiac devices like PMs, ICDs, and CRTs have added incremental value in improving heart failure outcomes especially in CHF patients with brady- or tachyarrhythmias [1, 22, 23]. Nevertheless, it has been shown that the conventional clinical practice of routine IO appointments every 6–12 months with additional unscheduled appointments due to worsening of CHF or device malfunctions is ineffective and therefore antiquated [24, 25].

Because CHF decompensation starts weeks before the acute exacerbation, early detection is one of the main goals in RM systems.

RM offers the possibility to assess relevant physiological parameters as heart rate variability (HRV), intrathoracic impedance, and patient activity level to provide information about the clinical status of the patient [26, 27]. It is known that individual parameters for itself have a poor predictive value of CHF decompensation [28]. Modern devices combine several measurements, allowing the implementation of predictive algorithms (e.g., TRIAGE-HF PLUS by Medtronic or HeartLogic by Boston Scientific) to identify patients at increased risk of CHF decompensation [29, 30].

However, inconsistent results in the improvement of RM of CIEDs have been found yet. Several non-randomized trials showed considerable outcome benefits including all-cause mortality [31, 32], whereas most randomized control trials (RCTs) showed neutral effects [8, 33].

In 2015, Parthiban et al. conducted a meta-analysis of nine RCTs, involving 6469 ICD or CRT-D patients, who were randomized to conventional in-office (IO) follow-up

Fig. 1 Examples of currently available remote monitoring systems (**A** CardioMessenger Smart Homemonitoring system, BIOTRONIK SE & Co. KG., Berlin, Germany; **B** St. Jude Medical, Abbot Merlin@ Home™ Transmitter; © 2022 Abbbott; **C** LATITUDE™ Home Monitoring System; Boston Scientific. Image provided courtesy of Boston Scientific. ©2022 Boston Scientific Corporation or its affiliates. All rights reserved **D** Medtronic CareLink™ System, Medtronic

and RM [7]. The authors found no significant differences in terms of all-cause mortality (OR 0.83, $p = 0.285$), CV mortality (OR 0.66, $p = 0.103$), and hospitalization (OR 0.83, $p = 0.196$). However, a reduction in all-cause mortality was detected in three trials using RM with daily verification and transmission (OR 0.65, $p = 0.021$). Of those three investigations, only the IN-TIME trial reported a significant reduction of both, all-cause (HR 0.36, $p = 0.004$) and CV mortality (HR 0.37, $p = 0.012$) [34•]. Although in all three studies the probability of receiving any ICD shock was similar in both groups (OR 1.05, $p = 0.86$), the incidence of inadequate shocks was reduced in RM patients (OR 0.55, $p = 0.002$) [7].

In 2016, Klersy et al. published a meta-analysis including three additional RCTs, which showed no significant effect of RM on all-cause (relative risk 0.90, $p = 0.41$) and CV mortality (relative risk 0.93, $p = 0.80$) or cardiac hospitalization (relative risk 0.96, $p = 0.60$). However, contrarily to the

IN-TIME trial, the authors did not consider the frequency of RM data transmission in their analysis [35].

In the MORE-CARE trial, 865 CRT-D patients were randomized to RM with automated alerts for fluid overload by means of intrathoracic impedance, atrial tachyarrhythmias and system integrity, or IO follow-up alone [36]. The primary endpoint, the composite of death, CV hospitalization, and device-related hospitalization, did not differ significantly between the two randomization groups after 2 years of follow-up (HR 1.02, $p=0.89$). Similarly, the individual endpoint components of all-cause mortality (HR 1.13, $p=0.59$), CV hospitalization (HR 0.96, $p=0.80$), and device-related hospitalization (HR 0.89, $p=0.74$) were not different [36].

In the OptiLink-HF trial, 1002 CHF patients with new implanted ICD (37%) or CRT-D (63%) were randomized to RM or to conventional treatment without RM. In the RM group, a daily check of alerts for fluid overload, which led to a specified clinical assessment and treatment, was conducted [37]. No significant difference was found regarding the combined primary endpoint of all-cause death and CV hospitalization (HR 0.87, $p=0.13$). The same result was observed concerning both CV mortality and hospitalization due to CHF worsening. Thus, in the OptiLink-HF trial, intrathoracic impedance (IIM) did not significantly improve outcomes in ICD or CRT-D patients with advanced CHF [37].

The poor efficacy of IIM could be explained by some factors, such us transmission failure of RM data, low patient adherence, and insufficient performance of the fluid detection algorithm [2].

Boehmer et al. studied a combination of additional algorithms such as thoracic impedance, heart sounds, relative tidal volume, activity response, heart rate, and respiratory rates. A 70% sensitivity of predicting impending CHF decompensation has been shown combining those indexes [38]. This multiple biosensor algorithm was further evaluated in the MANAGE-HF trial by Hernandez et al. showing promising results in terms of early detection of CHF decompensation [39•].

Other ongoing studies as PREEMPT-HF will add substantial information about the clinical usefulness and effectivity of RM in decision-making compared to conventional care [40].

Detection of Cardiac Arrhythmias

Alongside the detection of life-threatening arrhythmias, one of the main contributions of RM is early detection of atrial arrhythmias (AAR), especially atrial fibrillation (AF), which expose patients to the risk of thromboembolic events, worsening of CHF, inappropriate ICD shocks, or loss of biventricular stimulation [41–43].

With RM, physicians might have the opportunity to initiate anticoagulation, where appropriate, and to optimize rate or rhythm control therapies preventing stroke- or AF-related CHF decompensation due to early detection of AF.

In the In-TIME trial, this was discussed to be a key mechanism of benefit where, on subgroup analysis, RM primarily improved outcomes for CHF patients with a history of AF, although this effect was driven by a reduction in all-cause mortality, with no rhythm-specific change in hospitalization [34•].

In the REM-HF trial, Zakeri et al. focused on patients who had device-detected AF in the first year of follow-up. The trial had the goal to evaluate the potential impact of RM on mortality and hospitalization risk by comparing patients with AF to patients in stable sinus rhythm. The use of RM in AF patients was not associated with a reduction in all-cause or cardiovascular mortality. Surprisingly, an increased risk of recurrent cardiovascular and heart failure-related hospitalizations in patients with persistent AF has been observed [44].

Although the authors concluded that RM provided no benefit for patients with CHF compared to usual care, the study showed some interesting issues that might be causative for the neutral outcome. Over one third of the patients transmitted data for less than 75% of the weeks, implying a weak patient adherence. Moreover, centers were overloaded by unfiltered data. For example, approximately only 1% of the data led to a medical attention reflecting the technical and structural limitations of remote monitoring [45].

Although RM theoretically should be more effective in detecting AAR than IO follow-up, due to the continuous rhythm surveillance, concerning data are rather conflicting.

In 2015, Parthiban et al. reported no statistically significant change in the prevalence of AAR detection between RM and IO follow-up (OR 1.24, $p=0.203$). However, a significant decrease in the time to event detection and clinical decision was noted with RM compared to IO follow-up ($p<0.001$) [7].

In 2017, Amara et al. found similar results in a cohort of 595 pacemaker carriers, which were randomized to activated RM (RM-ON) and disactivated RM (RM-OFF). AAR could be detected in 28% of RM-ON and 22% of RM-OFF group ($p=0.06$). Time to AAR detection and treatment was shortened by 44% in the RM-ON group (HR 0.565, $p=0.01$). Thus, patients with activated RM were diagnosed and treated earlier for AAR than patients with disactivated RM, experiencing a lower AAR burden [46].

Contrarily, Lima et al. conducted a study randomizing 300 elderly patients after PM implantation to RM and controls. No significance difference in AAR detection was found between the two groups ($p=0.36$). Additionally, there was no difference in time to detect the first AF episode in the two groups. However, the median time to detect AF

recurrence in the RM group was lower than in the control group ($p = 0.004$) [47].

A more recent meta-analysis conducted in 16 RCT of patients with CIED or wearable device (WD) reported that RM, compared to IO follow-up, significantly reduced the risk of stroke, which may be due to the reduced time interval between AAR onset and therapeutic intervention [48]. Notably, a higher detection rate of AAR was only noted in patients with wearable devices.

Remote Hemodynamic Monitoring

In the past two decades, different technologies of remote hemodynamic monitoring have been studied. Most evidence is related to the CardioMEMS™ pulmonary artery pressure sensor (Micro-Electro-Mechanical HF System, Abbott Medical, Inc., Abbott Park, IL, USA) which requires no leads or batteries. It is a paper clip-sized device which is directly implanted into the pulmonary artery and concurrently powered and interrogated via an external antenna (Fig. 2). The sensor allows for direct measurements of the pulmonary artery pressure which increase is an early sign of imminent cardiac decompensation [49].

In the CardioMEMS Heart Sensor Allows Monitoring of Pressure to Improve Outcomes in NYHA Class III Heart Failure Patients (CHAMPION) trial, 550 patients with CHF, regardless of left ventricular ejection fraction, were randomized to 2 groups, one in which the clinicians used daily measurement of pulmonal arterial pressure (PAP) in addition to standard of care (treatment group; *n* 270) versus standard of care alone (control group; *n* 280) [50••]. The primary endpoint was the rate of heart failure hospitalization over 6 months. There was a significant reduction of the primary endpoint, from a rate of 0.44 in the control group to 0.32 in the treatment group (relative risk reduction, 28%; *p* 0.0002). Additionally, there was a reduction of 37% in the relative risk of heart failure hospitalizations compared with the control group in the follow-up period (Table 1).

An important subgroup analysis of the CHAMPION trial demonstrated significant efficacy in patients with heart failure and a preserved ejection fraction. The primary efficacy endpoint of heart failure hospitalization rate at 6 months was 46% lower in the treatment group compared with the control group (incidence rate ratio 0.54; $p < 0.0001$). During follow-up, the hospitalization rate was 50% lower (incidence rate ratio 0.5; $p < 0.0001$) [51].

Other important subgroups of CHAMPION patients have been analyzed retrospectively. Taken together, these analyses demonstrate the safety and effectiveness of PAP-guided heart failure therapy in patients with a history of myocardial infarction, secondary pulmonary hypertension, and chronic obstructive pulmonary disease and in those with chronic kidney disease [52–54].

In the multicenter, single-blinded Guide-HF trial, more than 1000 patients with heart failure NYHA II-IV, irrespective of their ejection fractions, were included. The primary endpoint was a composite of total mortality and total heart failure events. Although PAP-guided therapy management of heart failure did not result in a lower primary endpoint, a

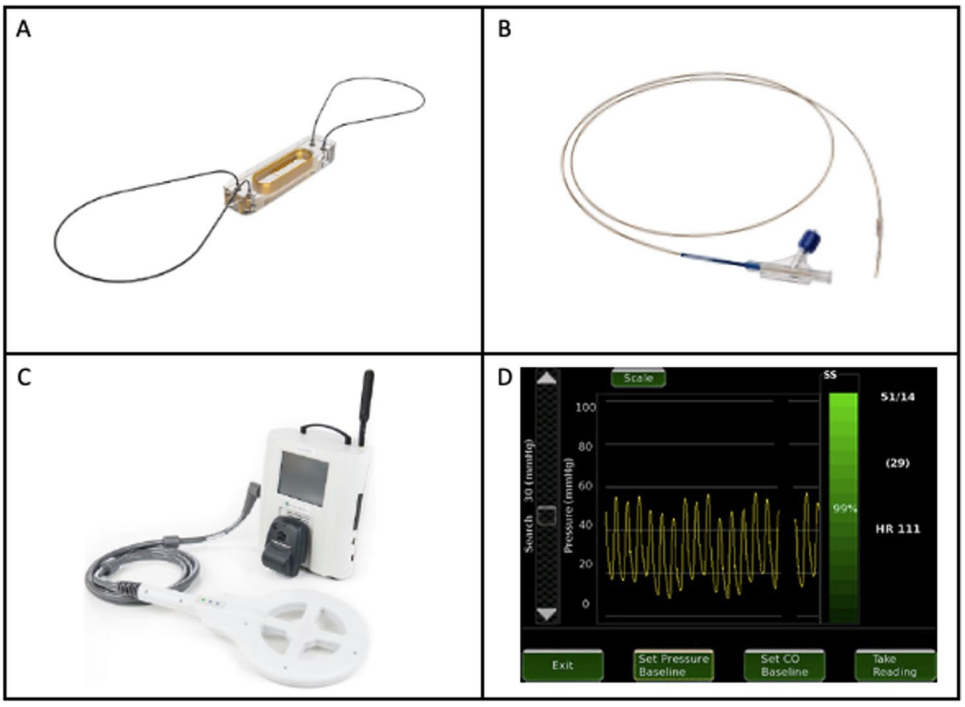

Fig. 2 CardioMEMS™ HF system (**A** CardioMEMS™ PAP sensor; **B** CardioMEMS™ delivery catheter; **C**, **D** Hospital Electronics System CardioMEMS™ HF System Model CM3000; Micro-Electro-Mechanical HF System, Abbott Medical, Inc., Abbott Park, Illinois, USA, © 2022 Abbbott)

Table 1 Current AHA/ACC/HFSA and ESC Guidelines according to remote monitoring with cardiac implantable electronic devices in heart failure [1, 23]

2022 AHA/ACC/HFSA Guideline for the Management of Heart Failure		
Recommendations	**Class**	**Level**
In selected adult patients with NYHA class III HF and history of a HF hospitalization in the past year or elevated natriuretic peptide levels, on maximally tolerated stable doses of GDMT with optimal device therapy, the usefulness of wireless monitoring of PA pressure by an implanted hemodynamic monitor to reduce the risk of subsequent HF hospitalizations is uncertain.	IIb	B

2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure		
Recommendations	**Class**	**Level**
Monitoring of pulmonary artery pressure using a wireless haemodynamic monitoring system may be considered in symptomatic patients with HF in order to improve clinical outcomes.	IIb	B

pre-COVID-19 analysis indicated a possible benefit in the pre-COVID-19 period primarily driven by lower hospitalizations compared with the control group (HR 0.81, 95% CI 0.66–1.00; $p = 0.049$) [55].

Whereas most of the studies referring to the CardioMEMS PAP sensor were published in the USA, two European studies in the UK and Germany recently have shown a likely added benefit in NYHA III class patients with a 82% and 62% reduction in CHF annualized hospitalization rates, respectively [56, 57•].

In addition to those remarkable results reflecting the potential of a PAP-guided therapy, several studies showed that CardioMEMS is also effective in terms of comprehensive heart failure cost reduction due to less hospitalization [58, 59].

The ongoing prospective, randomized, open, and multicenter trial PASSPORT-HF examines the efficacy of a pulmonary pressure monitoring in patients with CHF NYHA class III irrespective of ejection fraction and will provide important additional evidence [60].

Implantable Loop Recorder (ILR)

ILR are small subcutaneous implantable devices which provide a long-term continuous ECG monitoring (Fig. 3). Inserted close to the 4th intercostal space, an electrogram, corresponding to lead V2 or V4, is detected by two electrodes integrated at the ends of the devices. Complications of ILR implantations are quite rare, i.e., RIO 2 investigators reported a complication rate of < 1% irrespective of a hospital or ambulatory setting [61, 62]. Currently available ILRs are able to automatically transmit recorded data wirelessly by cell phone or via the provided connectivity hardware to a database of the attending physicians for further evaluation.

Established indications for ILR include unexplained syncope, palpitations, and AF detection [63].

For the diagnostic of palpitation, ILR are indicated in selected cases of severe infrequent symptoms, when other ECG monitoring technologies fail to identify the cause [64].

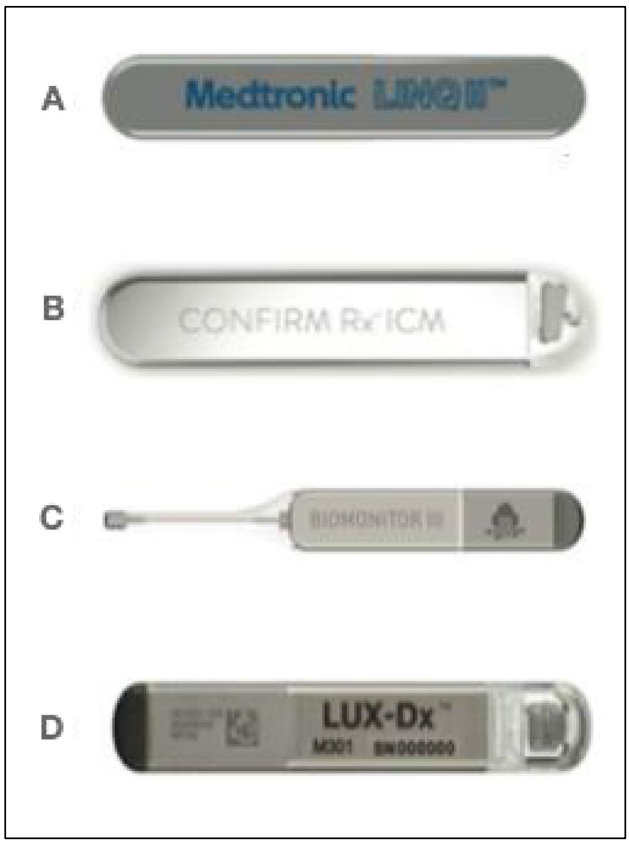

Fig. 3 Examples of currently available insertable loop recorders (**A** Medtronic Linq II™; **B** St. Jude Medical Confirm Rx™; © 2022 Abbbott; **C** Biotronik Biomonitor III™; **D** Boston Scientific LUX-Dx™. Image provided courtesy of Boston Scientific. ©2022 Boston Scientific Corporation or its affiliates. All rights reserved)

Most devices are equipped with automated algorithms for the specific recognition of AF, based on R-R wave interval stability parameters or p wave detection failing [65].

Although these algorithms have good sensitivity, the false positive rate is not negligible and requires physicians to personally evaluate the electrograms.

All current guidelines underscore that the decision to implant an ILR should consider patient's characteristics,

frequency of syncope, previous diagnostic work-up, and probability of arrhythmic causes [66–68] (Table 2). Evidence for ILR in unexplained syncope has been demonstrated in several RCT and observational studies [69–71].

In the setting of AF detection, ILR are generally used to evaluate the efficacy of medical or catheter ablation treatment and to exclude AF as cause of cryptogenic stroke. For detection of subclinical AF after stroke, current guidelines agree on a prolonged ECG monitoring. However, there is no specification of timing and method of monitoring [65].

In the last years, several studies have evidenced a strong association between subclinical AF, especially that of long duration, and increased risk of ischemic stroke. However, a causality could not be proved [65, 72–77].

In a multicenter RCT, Svendsen et al. randomized, in a 1:3 ratio, 6004 subjects without a history of AF and at least one risk factor for stroke, to ILR monitoring or usual care. AF was diagnosed significantly more often in the ILR than in the control group ($p < 0.0001$). However, after initiation of oral anticoagulation therapy in all study subjects, no differences in term of new strokes were detected in the two study groups. The results imply that not all episodes of atrial fibrillation might be associated with a higher risk [78••].

One of the most emblematic RCT for the detection of subclinical AF after cryptogenic stroke or TIA was the Crystal-AF Trial, in which 441 patients were randomized to ILR or standard of care monitoring in a 1:1 ratio [79••]. The primary and secondary endpoints were time to detection of AF, lasting for 30 s or longer at 6 and 12 months, respectively (8.9% vs 1.4% and 12.4% vs 2%). In the ILR arm, the median time to AF detection was 84 days. In a secondary study of Crystal-AF prolonging the follow-up to 3 years, the cumulative AF detection rate was 21.1% at 24 months and 30% at 3 years in the ILR group versus 3% and 3% in the control group. Thus, subclinical AF was detected significantly more often by ILR than by standard of care monitoring. The median time to AF detection was 8.4 months [80].

More recently, Ziegler et al. conducted a prospective observational study to define the incidence of subclinical AF in patients after cryptogenic stroke. Using a database of more than 1200 subjects after ILR implantation and a follow-up of 2 years, the authors reported a median time to AF detection of 112 days [81].

In light of these results, for subclinical AF detection, experts recommend currently a longer monitoring than the 30 days indicated in the past [82, 83]. This is more easily to be made by ILR than by standard of care monitoring using, e.g., Holter, external loop reorders or mobile cardiac telemetry monitors.

All these studies failed to prove a temporal relation between AF detection and further ischemic strokes as well as a clinical benefit of a subsequent oral anticoagulation therapy after AF detection in preventing ischemic events.

Wearable devices (WDs) have recently been shown to be capable of detecting rhythm disturbances, such us AF [84•]. It is therefore plausible to imagine, that in the near future, WD might replace ILRs for some specific indications. However, WDs have not yet been extensively used in clinical routine. Furthermore, no studies have yet been conducted to compare these devices to ILRs.

One aspect to take into consideration is that the increasingly extensive use of simple monitoring systems could lead to a data overload exceeding the assessment capabilities of medical facilities.

Table 2 Current AHA/ACC/HFSA and ESC Guidelines according to remote monitoring with cardiac implantable electronic devices in patients with syncope [67, 68]

2022 AHA/ACC/HFSA Guideline for the Evaluation and Management of Patients With Syncope		
Recommendations	**Class**	**Level**
To evaluate selected ambulatory patients with syncope of suspected arrhythmic etiology, an ICM can be useful.	IIb	B

2018 ESC Guidelines for the diagnosis and management of syncope		
Recommendations	**Class**	**Level**
ILR is indicated in an early phase of evaluation in patients with recurrent syncope of uncertain origin, absence of high-risk criteria, and a high likelihood of recurrence within the battery life of the device.	I	A
ILR is indicated in patients with high-risk criteria in whom a comprehensive evaluation did not demonstrate a cause of syncope or lead to a specific treatment, and who do not have conventional indications for primary prevention ICD or pacemaker indication.	I	A
ILR should be considered in patients with suspected or certain reflex syncope presenting with frequent or severe syncopal episodes.	IIa	B
ILR may be considered in patients in whom epilepsy was suspected but the treatment has proven ineffective.	IIb	B
ILR may be considered in patients with unexplained falls.	IIb	B

Challenges and Future Directions

Healthcare is developing towards a more patient-focused model (Fig. 4). Despite the big potential in better addressing healthcare requirements in this context, allowing for early medical response to device alerts RM is still underused in clinical practice [2].

Future developments should focus on technologies which could help to overcome the actual limitations of RM, namely, filtering the large amount of transmitted data to triage patients at risk improving feasibility and efficiency. Artificial intelligence, e.g., which additionally could support diagnostic and treatment decisions including predicting arrhythmias or other cardiovascular diseases, could play a key role in the near future according to that challenge [85, 86]. Supplementary, to streamline the evaluation of RM data, it would be desirable to use a platform capable of integrating data from different manufacturers.

Wearable devices have recently been shown to be able to detect arrhythmias in unselected collectives of the population. Therefore, it is legitimate to think that in the near future, RM could be entrusted to WDs in some if not the majority of patients without an indication for CIEDs. However, data on efficacy of WD in clinical routine is still limited, and further studies are needed in this setting.

Conclusions

The use of remote monitoring in PM, ICD, and CRT devices, complementary to IO follow-ups, has led to an increase in patient satisfaction, an improvement in their quality of life, and greater adherence to the follow-up schedule. Instead, RCTs in this setting demonstrated neutral or discordant results regarding patient outcomes. Other devices with the sole purpose of monitoring, such as ILR and CardioMEMS, certainly provide an improvement in early diagnostics especially in CHF patients.

Daily data transmission seems to be determinant to make RM able to improve patient outcome. However, a large amount of data must be continuously evaluated by the healthcare staff, who must react promptly by offering patients the necessary therapy. Centers able and willing to offer remote monitoring must therefore provide sufficient specialized personnel with the necessary technical equipment that must be updated continuously. Thus, it is of primary importance to carefully select patients, favoring those at risk, such as patients with more depressed LVEF, which are likely to benefit most from RM.

Furthermore, the patient's potential adherence should be also considered a selection factor for RM, as this is directly correlated with the chances of survival.

The daily review of such amount of RM data could suggest an increase in costs. Conversely, reducing IO follow-up

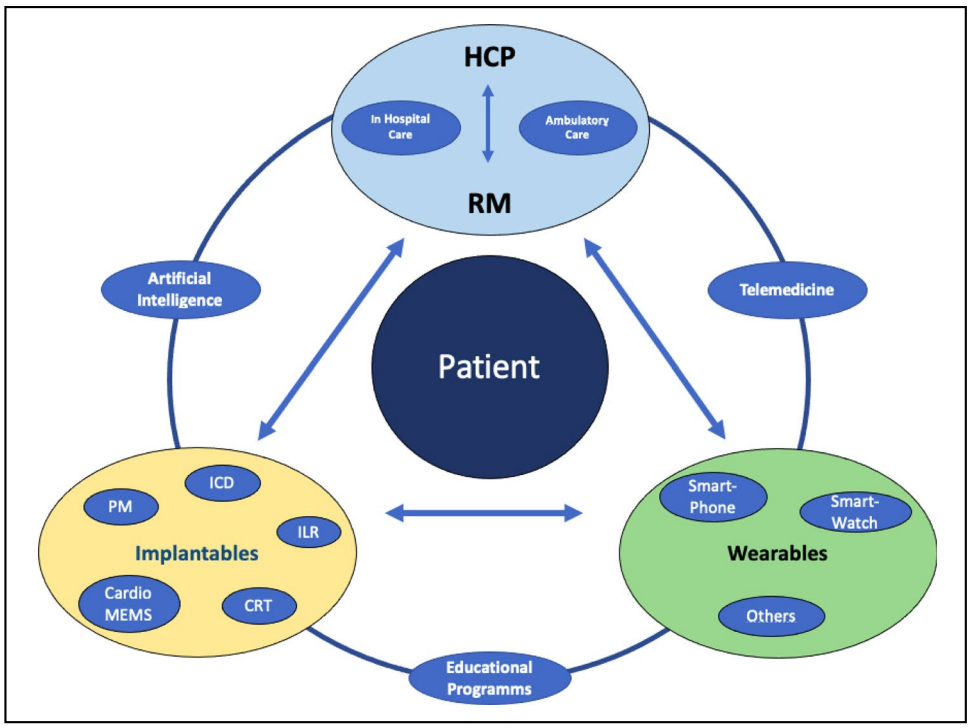

Fig. 4 Centralized patient healthcare model (healthcare provider (HCP))

visits and hospitalizations could ultimately lead to a reduction in the overall costs.

Ultimately, future technical developments as integration of artificial intelligence algorithms will provide crucial solutions to overcome current problems in feasibility and efficiency of RM.

Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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