



Remote Patient Monitoring: What Have We Learned and Where Are We Going?

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Abstract

Purpose of Review Remote monitoring (RM) of cardiac implantable electronic devices (CIEDs) is an important part of patient follow-up. The increasing number of patients with CIEDs and the recent pandemic pose several challenges for already limited device clinic resources. This review focuses on recent evolutions in RM and identifies future needs to improve RM.

Recent Findings RM has been associated with multiple clinical benefits, including improved survival, early detection of actionable events, reduction in inappropriate shocks, longer battery lives, and more efficient healthcare utilization. The survival benefit was driven by studies using alert-based continuous RM with daily transmissions and fast reaction times. Patients report a high satisfaction rate without significant differences in quality of life between RM and in-office follow-up. The increasing workload, due to the increasing number of CIEDs implanted with daily remote transmissions, results in several challenges for the future of RM. RM requires appropriate reimbursement for RM device clinics to optimize patient/staff ratios, including sufficient non-clinical and administrative support. Universal alert programming and data processing may minimize inter-manufacturer differences, improve the signal-to-noise ratio, and allow the development of standard operating protocols and workflows. In the future, programming by remote control and true remote programming may further improve remote CIED management, patient quality of life, and device clinic workflows.

Summary RM should be considered standard of care in management of patients with CIEDs. The clinical benefits of RM can be maximized by an alert-based continuous RM model. Adapted healthcare policies are required to keep RM manageable for the future.

Keywords Remote monitoring · Remote programming · Remote control programming · Cardiac implantable electronic devices · Pacemaker · Implantable cardioverter-defibrillator

Introduction

Remote monitoring (RM) is an important part of follow-up in patients with cardiac implantable electronic devices (CIEDs) [1]. The increasing number of CIEDs implanted, as well as unexpected challenges such as the COVID-19 pandemic, have

resulted in high demands on in-person services and a shift towards virtual outpatient clinics [2, 3]. RM requires cooperation of various indispensable components (Fig. 1). First and foremost, the patient has a central position in RM and the patient's cooperation and adherence to RM are crucial to obtain the associated clinical benefits. Second, the remote device clinic which covers the multidisciplinary team involved with RM including clinical, non-clinical, and administrative staff. Third, the home monitor and the remote monitoring platform [1]. The home monitor is the remote telemetry device which is either positioned strategically in the proximity of the patient (individual-based RM) or the monitor is enrolled to a specific site and can be used to collect data for many individual patients (site-based RM) [4]. These data can be accessed by the remote device clinic staff using the RM platform. A limited overview of RM systems is provided in Table 1. Lastly, RM refers to automated transmissions of pre-specified alerts and should be differentiated from remote follow-up, which refers to scheduled

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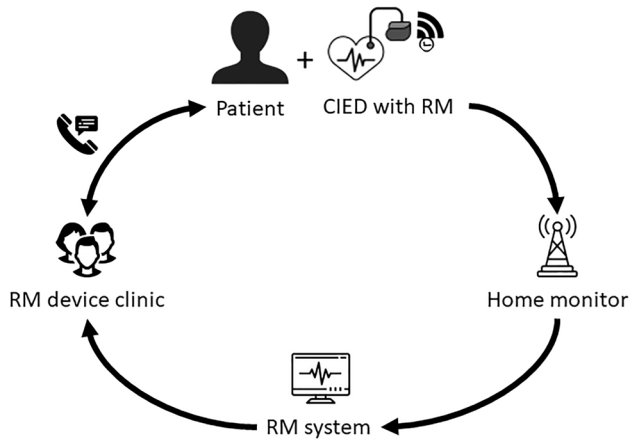


Fig. 1 Remote monitoring components. In RM the patient with a CIED is central. By wireless connection data from the CIED is transmitted to the home monitor and subsequently from the home monitor to the RM system. The device clinic team reviews all remote transmissions and communicates with the patient. The patient can also contact the device clinic team autonomously. Abbreviations: CIED: cardiac implantable electronic device; RM: remote monitoring

transmissions imitating routine in-person clinic visits [1, 5]. Importantly, some manufacturers have devices that provide or can be programmed to provide daily remote transmissions (Table 1). Daily updates, to confirm patient connectivity and absence of alerts, allow near continuous RM and may facilitate an alert-based RM follow-up, a fully remote patient management strategy [6•, 7•]. In this review, we will discuss recent evolutions in RM, practical considerations in RM, and identify barriers to facilitate optimal RM.

Benefits of Remote Monitoring

RM has been associated with several clinical and economic benefits for both physicians, patients, and healthcare systems.

Mortality

Several randomized clinical trials (RCT) have studied the impact of RM on survival. In 2014, the IN-TIME trial randomized 664 patients with heart failure and an implantable cardioverter-defibrillator (ICD) or cardiac resynchronization defibrillator (CRT-D) 1:1 between automated continuous RM and standard of care without RM [8]. The 1-year all-cause mortality was significantly lower in the RM group when compared to the standard of care group (3.4% vs. 8.7%, $p=0.004$) [8]. A meta-analysis by Parthiban et al. included data from 9 RCTs, corresponding to a total of 6469 patients [9••]. While the overall analysis did not find a significant survival benefit for RM (OR 0.83, 95% CI 0.58–1.17, $p=0.285$), they identified a potential survival benefit when using continuous RM (Biotronik Home Monitoring, Biotronik, Germany) [9••]. This finding was confirmed in the pooled analysis of the 3 RCTs using continuous RM (IN-TIME, ECOST, and TRUST) [7•, 8, 10, 11]. At 1-year follow-up, continuous RM was associated with a 1.9% reduction in all-cause mortality (95% CI 0.1–3.8%, $p=0.037$) [7•]. Until now, studies with non-continuous RM have failed to show a survival benefit.

The survival benefit of RM in CIEDs was further confirmed in large, real-world registries [12, 13, 14•]. The ALTITUDE survival analysis reported survival data from 194 006 patients with heart failure and showed a significant survival benefit of RM in both ICD and CRT-D patients [12]. Later, Varma et al. reported on the association between survival and time in continuous RM in 269 471 patients [14•]. Besides a significant survival benefit in patients with continuous RM, they also found that patients with $\geq 75\%$ continuous remote transmission had a significant lower all-cause mortality compared to those with $< 75\%$ continuous remote transmissions [14•]. This finding was present not only in patients with ICDs and CRT-Ds but also in patients with pacemakers [14•].

Table 1 Overview of remote monitoring system per manufacturer

Manufacturer	Abbott	Biotronik	Boston Scientific	Medtronic	MicroPort
Remote monitoring system	Merlin.net™	Home Monitoring™	Latitude™	CareLink™	SmartView™
Home monitor	Merlin@Home™	CardioMessenger	Latitude™ NXT Communicator	MyCareLink™	SmartView™
Frequency of transmissions	- Scheduled or daily - Programmed alerts	- Daily - Programmed alerts	- Scheduled or daily - Programmed alerts	- Scheduled - Programmed alerts	- Scheduled or daily - Programmed alerts
Programmability of frequency of transmissions	Yes	No	Yes	Yes	Yes
Real-time intracardiac electrogram at remote follow-up	30 s	30 s	10 s	10 s	7 s

Quality of Life and Patient Satisfaction

Three RCTs reported on quality of life comparing RM and standard of care group with routine in-office visits [15–17]. None of these studies reported any significant difference in physical, mental, and overall quality of life using the SF-12 or SF-36 questionnaire [15, 16]. More data are available on patient satisfaction and preferences with regards to RM. While all studies reported excellent patient satisfaction rates for RM, in 2 RCTs there was no significant difference in patient satisfaction when comparing RM versus in-clinic only follow-up [18–24]. Several surveys reported a patient preference for RM over in-office visits [22–24]. Timmermans et al. found that only 19% of their patients preferred in-office follow-up [22]. Reasons to prefer in-office follow-up were human contact with physicians, trust, short travel distance to the hospital, and prior negative experiences with RM [22].

Early Detection of Actionable Events

Actionable events can be defined as any clinical or device-related event detected by RM of which short-term management may improve a patient's outcome. As such, this does not only concern patients with ICDs, but also patients with pacemakers or implantable loop recorders (ILR). Observational data have shown that only 6% of scheduled in-office follow-up visits resulted in device reprogramming or changes in patient management [25]. Additionally, the time from event detection to medical intervention was significantly shorter in patients with RM, and could even be reduced to 1 day using continuous RM [15, 26].

There are three main advantages to RM with regards to detection of events. In the first place, RM allows early detection of device and lead malfunctioning, such as lead failure or battery depletion, which is particularly useful for CIEDs on advisories or recall [1, 27, 28]. The continuous surveillance resulted in a significant reduction in inappropriate shocks and symptomatic pacing inhibition in patients with lead failure [29]. The benefit of RM may even be highest immediately following implant where data from the TRUST trial showed earlier detection of actionable events requiring device reprogramming or lead revision without increasing the incidence of non-actionable events [30].

Second, RM allows early notification and adjudication of ICD therapies. Differentiation between appropriate and inappropriate ICD interventions is particularly useful to guide the treatment intervention required. While some actionable events might require simple pharmacological optimization or device reprogramming, other might require further diagnostic exams, electrical cardioversion, or surgical intervention [31]. Due to early detection of actionable events, RM has been found to reduce the number of inappropriate ICD

shocks and even prolong battery longevity with approximately 12% [32–34].

Finally, RM facilitates early arrhythmia detection and for ILRs this is even the main indication for implanting the device [35]. Early detection of atrial fibrillation, or so-called subclinical atrial fibrillation, and quantification of arrhythmia burden by CIEDs is routinely used in clinical practice and in RCTs on atrial fibrillation [35, 36]. While subclinical atrial fibrillation in CIED patients has been associated with an increased risk of stroke and a meta-analysis suggested a benefit in stroke prevention with RM, results from RCTs on the use of anticoagulation in RM mediated detection of atrial fibrillation (e.g. ARTESIA trial [ClinicalTrials.gov Identifier: NCT01938248]) are still awaited [37–39].

Healthcare Utilization

RM shifts healthcare utilization from face-to-face in-office visits to remote patient contact by using phone visits and automated messages (Table 2). The At-Home study reported a 70% reduction in in-office visits with a significant decrease in staff workload [40]. In the RM-ALONE study the reduction in in-office visits was even 83% [41]. In the TRUST study, a fully remote alert-based RM was associated with a reduction of 81% in nonactionable events, while actionable events remained unchanged [6••]. This all occurred without an increase in major cardiac events [6••, 40, 41]. Furthermore, a recent cost-consequence sub-analysis of TRUST showed that an alert-based RM strategy was associated with a significant lower cost compared to in-person evaluations only and a remote follow-up strategy [42••]. The Euro-Eco trial reported a more efficient healthcare utilization with a reduction in follow-up visits despite an increase in unscheduled visits and fewer hospitalization with a shorter length of stay [43].

In a Health Technology Assessment, blended RM models combining RM with scheduled in-office follow-up were less costly and more effective in patients with pacemakers. Among patients with ICDs, the cost of the blended RM model was higher but also increased the quality-adjusted life years [44]. An economic analysis in the TARIFF study showed that RM was cost-effective for the patients, caregivers, and the health care systems [45]. Therefore, RM has the potential to be cost-effective depending on the local reimbursement policies.

Heart Failure Monitoring

There has been continuous interest in using RM as a tool in heart failure monitoring, more specifically to use

Table 2 Healthcare utilization in major RM trials

		COMPAS 2012 [15]	RM-ALONE 2019 [41]	At-Home 2020 [40]	TRUST 2021 [6●●]
Design	Population	DDD PM	VVI/DDD PM or ICD	VVI/DDD PM	VVI/DDD ICD
	Included subjects	<i>N</i> = 538	<i>N</i> = 445, 66.1% PM	<i>N</i> = 1274	<i>N</i> = 1339
	Randomization	1:1	1:1	1:1	2:1
	Intervention	Daily RM	Daily RM + remote FU q6m	Daily RM + in-office at 24 m	Daily RM + remote FU q3m
	Control	As per physician's discretion	Hybrid remote FU + in-office q6m	Hybrid remote FU + in-office q6m	In-office q3m
	Primary endpoint	Death, cardiovascular/device event requiring hospitalization	Death, stroke, cardiovascular/device event requiring surgery or hospitalization	Death, stroke, cardiovascular event requiring surgery	Reduction in non-actionable in-person evaluations
Endpoints*	Primary endpoint	17.3% vs. 19.1% (<i>p</i> = 0.63)	20.0% vs. 19.5% (<i>p</i> = 0.006 for non-inferiority)	10.9% vs. 11.8% (<i>p</i> = 0.001 for non-inferiority)	81% reduction (<i>p</i> < 0.001)
	All in-office visits	36.2% reduction	79.2% reduction	69.5% reduction	37.5% reduction (includes study initiation and end visit)
	Follow-up/year	1.0/year vs. 1.6/year (<i>p</i> < 0.001)	0.3/year vs. 1.5/year (<i>p</i> < 0.001)	0.5/year vs. 2.0/year (<i>p</i> < 0.0001)	2.5/year vs. 4.0/year (<i>p</i> < 0.001)
	Actionable events	62% vs. 29% (<i>p</i> < 0.001, includes all changes in management)	NA	1.6% vs. 1.4% of total (<i>p</i> = 0.81) 9.0% vs. 11.7% of unscheduled in-office visits (<i>p</i> = 0.42)	16.2% vs. 11.8% (<i>p</i> < 0.001)
	Economic analysis	NA	NA	11% reduction in total cost/year	13% reduction in total cost at 2 years

*Data are presented as intervention vs. control group or % reduction in the intervention group when compared to the control group

Abbreviations: *FU*, follow-up; *ICD*, implantable cardioverter-defibrillator; *NA*, not applicable; *PM*, pacemaker; *RM*, remote monitoring

measures of thoracic impedance as marker of congestion, as well as other cardiac markers to predict heart failure decompensation, hospitalization, and cardiovascular mortality [1]. Several recent studies showed comparable outcomes between RM-enabled heart failure management and conventional in-office follow-up, for example the REMOTE-CIED and the MORE-CARE trials [46, 47]. These studies focused predominantly on markers estimating lung fluid accumulation. The success of other studies could be explained by two main reasons [48, 49]. First, in the OptiLink HF trial, an appropriate response to alerts, defined as telephone contact within 2 days and follow-up contacts, was associated with a reduction in cardiovascular death and heart failure hospitalization [49]. Second, the MultiSENSE study performed multi-parameter heart failure assessment, including thoracic impedance, heart rate, and biventricular pacing percentage [48]. Furthermore, hemodynamic monitoring parameters with automated analysis of heart sounds and pulmonary artery pressures have been successfully used as well to manage heart failure and avoid hospitalizations [48, 50]. Taken together, the combination of novel markers with a rapid follow-up of these findings was needed to see the benefits.

Practical Remote Monitoring Considerations

Patient Education and Enrollment

Patient education is essential for CIED patients and should include the concept of remote monitoring. Patient education about RM should start before CIED implant and include essential knowledge on ensuring RM connectivity and RM compliance.

In an ideal scenario, RM enrollment is performed prior to hospital discharge, but this requires a continuous stock of RM receivers in the hospital while some providers prefer the RM receiver to be delivered at home. Due to technical circumstances, absence of primary caregivers in the hospital, and difficulty coping with the decision to implant a CIED, enrollment post-implant—either a virtual enrollment or enrollment at the first in-office visit—might be preferred. For ILRs, it is recommended to initiate RM prior to hospital discharge given the continuous availability of diagnostic data which may affect patient management [1]. As 1 out of 4 patients fail to initiate RM at home, a “handshake transmission” to verify a first successful remote transmission can be used [51].

The timing of patient enrollment is highly variable in studies and no direct comparison for any outcome has been performed. Mittal et al. studied the effect of time from implant to RM initiation on all-cause mortality in a national retrospective cohort of 106 027 patients with a CIED in the USA [52]. Of these, 62.3% had a first successful RM transmission within 91 days of implant, and this was associated with a 18% higher survival when compared to > 91 days from implant to first RM transmission [52]. This survival advantage with early RM transmission was present across all CIED types, but was greatest for patients implanted with CRT-D devices [52].

Remote Device Clinic Staff

The remote device clinic consists of a multidisciplinary team, including physicians, allied professionals, and administrative staff [1]. The increasing workload due to increasing number of patients with CIEDs and continuous RM, requires an efficient team-based organization with well-defined tasks and procedures [53]. The device clinic staff has several other essential tasks to complete on a continuous basis besides RM. These include patient education, assisting in CIED implant procedures, and in-office CIED visits. Reviewing RM transmissions is only a small part of managing a CIED patient on RM. Throughout the EuroEco trial, the required dedicated time to manage a RM patient did not differ significantly from a patient with in-office clinic visits [43]. The remote device clinic workflow includes transmission review and diagnosis, patient communication and clinical action, and electronic charting and billing (Fig. 2) [54]. These include numerous

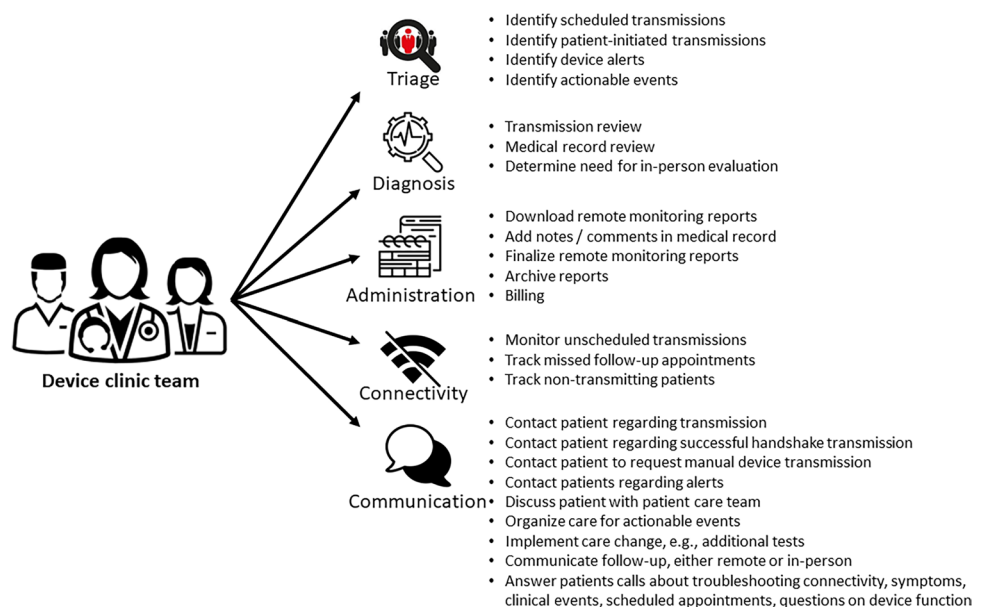
“invisible tasks,” such as phone calls, troubleshooting connectivity issues, alert triage, and scheduling in-office visits to address actionable events.

The workload burden also differs between CIED types, ranging between an estimated annual workload for a pacemaker of 0.8 h, up to 8.4 h for a patient with an ILR [54, 55]. Contemporary data show that while ILRs accounted 18.8% of CIEDs followed in the remote device clinic, they delivered > 50% of the alerts [56]. As such, the increasing use of ILRs results in a disproportionate increase in workload (Fig. 3). Dedicated workflows and decision-trees for each CIED type may be required.

Remote Monitoring Connectivity and Adherence

Consistent connectivity and patient adherence to remote monitoring are critical elements for the success of RM. The clinical benefit of RM is directly related to early detection of actionable events and a timely response by the remote device clinic. Therefore, patient connectivity should be monitored, and connectivity issues should be addressed as quickly as possible. Troubleshooting connectivity issues is a time-consuming process and was identified as one of the invisible tasks of the remote device clinic [54]. Furthermore, a prior problem with connectivity was identified as a reason for patient preference of in-office visits and was associated with low patient adherence [22]. Adequately trained staff and a dedicated workflow to address connectivity issues, including when to contact device manufacturers, are crucial to maximize RM connectivity and patient adherence.

Fig. 2 Overview of tasks performed by the remote device clinic staff. The remote device clinic staff performs numerous tasks which can be divided roughly into five categories: triage, diagnosis, administration, connectivity, and communication



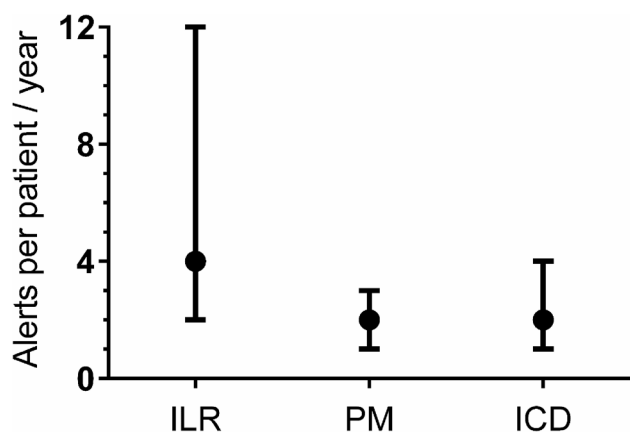


Fig. 3 Alerts per patient per year by CIED type. The graph illustrates the median number of alerts for patients with an ILR, PM, or ICD. ILRs are associated with a higher alert burden when compared to PMs and ICDs. Data are presented as the median and interquartile range. Based on data presented by O’Shea et al. [56]. Abbreviations: ICD: implantable cardioverter-defibrillator; ILR: implantable loop recorder; PM: pacemaker

Defining Actionable Events and Alerts

The programming of RM alerts and actionable events should be tailored to the patient and the CIED type [57]. Unfortunately, there is a large variability between manufacturers on the type and number of programmable alerts which makes it challenging to develop standardized workflows. In general, alerts concerning ICD therapies, lead integrity, and battery capacity should be identified as high-priority or critical alerts (Table 3) as immediate action is indicated and has been shown to be beneficial for the patient [8, 10, 26, 58, 59]. Other alerts should be tailored to the patient and CIED indication (Table 3). For example, in patients with CRT, loss of biventricular pacing warrants an alert while in patients without pacing indication, the ventricular pacing percentage should be monitored to reduce the risk for pacing-induced cardiomyopathy. To avoid repeating non-actionable events, alert programming should be adjusted once sufficient clinical data has been received. For example, new-onset atrial fibrillation warrants a first alert, but once the patient is anticoagulated and the atrial fibrillation is adequately managed, the alert should be adjusted to avoid repetitive non-actionable events.

Challenges in Remote Monitoring

Geographic and Socioeconomic Disparities

Data on geographic and socioeconomic disparities of RM availability and adherence are scarce. In 2013, Lau et al. presented an update on the use of RM in the Asia–Pacific

region describing large geographic disparities with limited use in South-East Asia and India, while RM was used in more than half of CIED patients in Japan [60]. Even when RM is set-up, RM availability does not equal adherence. Data from the USA showed significant geographic disparities in RM adherence, with up to 20% of patients not using their RM even when it is available [61]. Joint efforts by health care organization and manufacturers should focus on identifying barriers to remote monitoring availability and adherence, including socio-economic and geographical disparities.

Signal-to-Noise Ratio

It has been estimated that > 10 million scheduled remote transmissions would be generated annually if all patients in the USA with a CIED would use RM [62]. In the midst of this humongous workload of normal scheduled transmission, false alerts, and non-actionable events, there are a limited number of critical alerts and actionable events [63]. In a retrospective study, 16 560 RM transmission from 1849 patients with pacemakers, ICDs, or CRT-Ds were analyzed [63]. Of these transmissions, only 4.1% were critical events. The critical event rate that was lower in patients with a pacemaker (0.9%) compared to patients with an ICD (5.0%) and CRT-D (5.9%) [63]. These data illustrate that process optimization will be crucial in order to streamline the increasing workload of the remote device clinic and to keep it manageable. This requires appropriate staffing, dedicated workflows, and optimized alert programming.

Universal Data Formatting and Processing

Currently, RM alert options are highly variable between CIED manufacturers. This variability ranges from type and number of alerts independent of preferred clinician settings, to manufacturer-specific automated alert settings which results in the same event being reported as an event by one manufacturer but not by the other. Furthermore, the timing of transmissions differs significantly between manufacturers as some transmit whenever a patient is in range, while others only transmit at a preset time. This lack of harmonization makes it currently impossible to create standard operating procedure templates and RM device clinic workflows. The Heart Rhythm Society Interoperability Workgroup collaborates with the CIED vendors, electronic medical record vendors, and RM vendors aiming to develop standardized nomenclature and interoperability to evolve to a universal Implantable Device Cardiac Observation (IDCO) profile [64].

Table 3 Critical vs. non-critical RM alerts in pacemakers, ICDs, and ILRs

Type	Pacemakers	ICD	ILR
Critical	Device integrity	End of service/low battery voltage in pacemaker-dependent patients	End of service/low battery voltage
		Device reset or safety mode in pacemaker-dependent patients	Device reset or safety mode
Critical	Clinical	RV lead impedance out of range in pacemaker-dependent patients	RV lead impedance out of range
		Noise episode in pacemaker-dependent patients	Shock lead impedance out of range
Non-critical	Device integrity	Long charge time	
		VF detection/noise episode	
Non-critical	Clinical	ICD shock delivered	Pause/asystole > 6 s
			Tachyarrhythmia > 30 beats > 231 bpm
Non-critical	Device integrity	Elective replacement indicated	Elective replacement indicated
		RA/LV lead impedance out of range	RA/LV lead impedance out of range
Non-critical	Clinical	Pacing threshold out of range	Pacing threshold out of range
		MRI mode	MRI mode
Non-critical	Device integrity	Device reset or safety mode in pacemaker non-dependent patients	
		RV lead impedance out of range in pacemaker non-dependent patients	
Non-critical	Clinical	Noise episode in pacemaker non-dependent patients	
		RV pacing % > programmed value	RV pacing % > programmed value
Non-critical	Device integrity	Biventricular pacing % < programmed value	Biventricular pacing % < programmed value
		Detection of new-onset atrial fibrillation	Detection of new-onset atrial fibrillation
Non-critical	Clinical	Atrial burden > programmed value	Atrial burden > programmed value
		Ventricular high-rate episodes	ATP delivered
			Ventricular high-rate episodes

*Depending on the indication for ILR

Abbreviations: *ATP*, anti-tachycardia pacing; *bpm*, beats per minute; *ILR*, implantable loop recorder; *MRI*, magnetic resonance imaging; *LV*, left ventricle; *PM*, pacemaker; *RA*, right atrium; *RV*, right ventricle; *VF*, ventricular fibrillations

Reimbursement

Reimbursement of RM varies widely by country and may even vary within country by health jurisdiction [55, 65]. Reimbursement models also vary between capitation payments, fee-for-service, and global budgets. In a survey by the European Heart Rhythm Association, the single most reported barrier to implement RM in all patients with CIEDs was lack of reimbursement [66]. While all physicians considered RM a useful technology, it was mostly perceived as an increased workload for the entire team [66]. Several economic assessments have confirmed that RM is cost-effective, as in there are increased clinical benefits for additional costs that fall within country-specific, societally accepted thresholds for healthcare value

[44, 67, 68]. Given the continuously increasing workload in RM device clinic, implementation of appropriate reimbursement models adapted to local healthcare systems and taking into account added indirect workloads and appropriate staffing ratios, should be a priority.

The Future of Remote Monitoring

Towards Alert-Based Remote Monitoring

It has been recommended to interrogate CIEDs every 3 months, either in-person or remotely [1]. In most centers the standard practice for CIED follow-up is a blended strategy with annual or bi-annual in-office visits

in combination with RM (Fig. 4). The RM component can either be scheduled remote transmissions where RM is used to mimic a clinic visit, or continuous RM. Scheduled in-office visit leave interim events unattended until the next scheduled visit, therefore delaying treatment of potential actionable events. For scheduled remote transmissions, this will depend on RM programming. Thanks to advances in telecommunication technologies, contemporary RM systems are evolving to continuous RM where device and disease-related alerts are generated as and when they occur [5]. The available data steer the future of RM in the direction of continuous RM, which will minimize the time from detection of actionable events to clinical action [7•, 8, 10, 11]. Continuous RM may facilitate the implementation of alert-based RM, which is a combination of continuous RM with clinic visits prompted only by detection of actionable events, hence extending remote patient management beyond calendar-based follow-up (Fig. 4). Alert-based RM was necessitated during the recent COVID-19 pandemic and may replace structured calendar-based follow-up, whether it is in-office or remote [3, 6••]. RCTs have shown that

it is safe to extend the time interval between in-office visits up to 24 months for both pacemakers and ICDs in selected patients [6••, 10, 15, 30, 40, 41, 43, 69–71]. Conditions to be met for patients to be eligible for alert-based RM are consistent connectivity with near-perfect patient adherence and absence of cardiac comorbidities that may require more frequent follow-up.

Remote Programming and Remote Control Programming

Remote Programming

Experiences during the COVID-19 pandemic have reinforced the interest in remote programming. The optimal remote programming arrangement would be to deliver this care to the patient where they are, even if that is in their home. Current RM setups consist of unidirectional data transmissions between the CIED and the RM system. While technologically feasible, bidirectional communication with the ability to remotely reprogram the CIED is restricted due to cybersecurity and liability

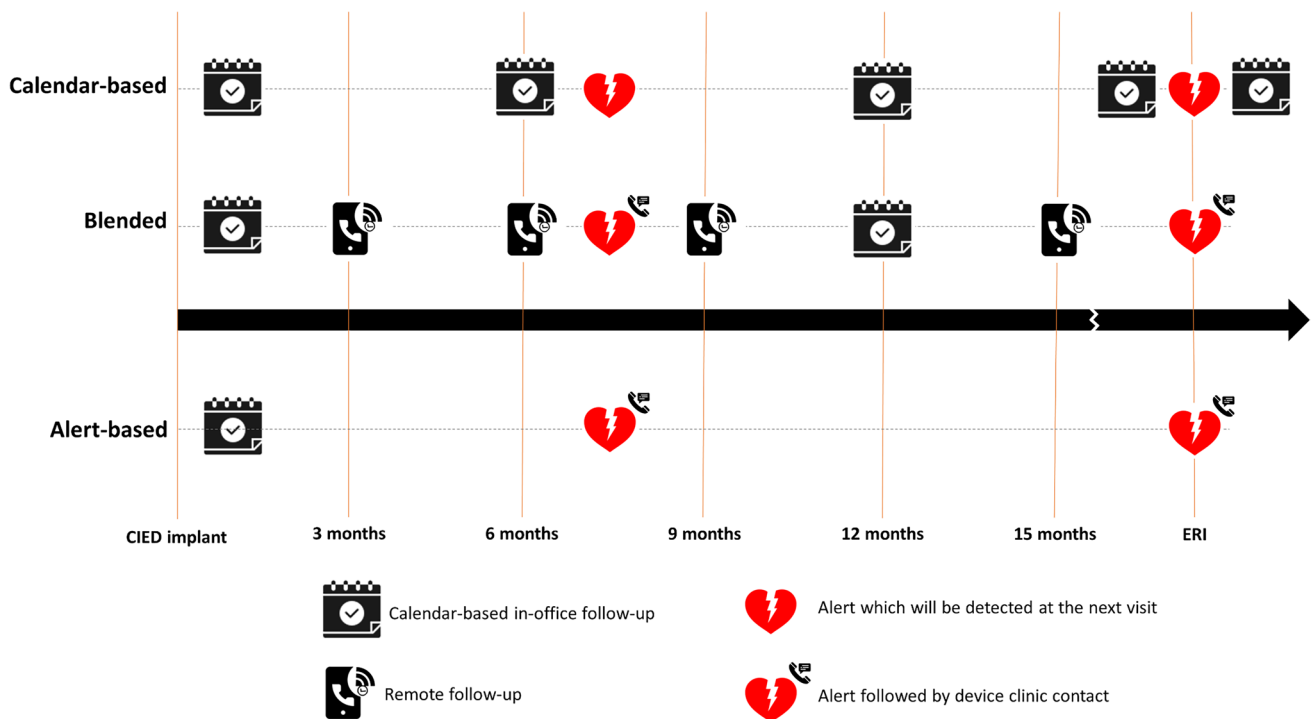


Fig. 4 Schematic presentation of scheduled and alert-based remote monitoring. Schematic presentation of three different types of CIED follow-up. Calendar-based follow-up consists of recommended bi-annual scheduled follow-up without RM. Therefore, alerts will either be diagnosed at the next in-person visit or upon clinical presentation due to symptoms associated with the alert. When the device approaches ERI, calendar-based follow-up is intensified to avoid end-of-service device behavior. The blended follow-up combines at

least annual calendar-based visits with scheduled remote interrogations. If alerts are activated these will be transmitted to the device clinic and trigger an actionable event managed by the device clinic team. Alert-based RM consists of continuous RM with clinic visits prompted only by detection of actionable events and may extend the time interval between in-office visits up to 24 months. Abbreviations: CIED: cardiac implantable electronic device; ERI: elective replacement indicated

concerns [72]. For example, in 2016, the Muddy Waters report outlined possible cybersecurity vulnerabilities that required firmware upgrades in St. Jude Medical (now Abbott) pacemakers [73]. While there have not been any reports of harm, several issues limiting the implementation of remote programming and potential mitigation strategies were identified [72]. First, the perceived and actual cybersecurity risk may be mitigated by using a closed loop communication system which requires physical action by both the patient and the physician prior to remote programming. Second, remote programming may result in a lack of clinical input by the bedside device clinic staff. Third, immediate feedback on the consequences of the altered programming will be lacking. The latter two issues may be mitigated by increased clinical surveillance.

True remote programming using bidirectional communication in the setting of a patient’s home remains challenging (Fig. 5). In a first step, the functionality of remote programming could be limited to minor alterations in CIED programming, such as rate response settings, in a subgroup of patients without major comorbidities who have shown near perfect RM connectivity and compliance. However, in the end, the patient’s personal preferences and trust in remote programming should be considered prior to implementing remote programming as part of standard care.

Remote Control Programming

Recent reports have confirmed the feasibility of an intermediate form of remote programming by acquiring remote control of CIED programmers (Fig. 5) [74•, 75–77]. This remote control programming setup requires the patient to go a hospital or clinic near their home (but not in their home), where the connection between the CIED and the programmer is initiated by a technician. Subsequently, a remotely located physician can acquire remote control of the programmer and perform a routine interrogation and reprogram the device. Kloosterman et al. and Siddamsetti et al. used the Medtronic (Minneapolis, US) remote control application which is compatible with their 2090 Medtronic programmer to perform remote device checks before and after respectively 50 and 209 magnetic resonance imaging scans [76, 77]. Ploux et al. used a custom multivendor solution which allowed them to perform remote interrogations in 110 patients (Abbott, Illinois, US; Biotronik, Berlin, Germany; and MicroPort, Shanghai, China), of which 55% were pacemaker dependent [74•]. Remote control programming was performed in about half of interrogations without any failure and a time lag < 1 s [74•]. These setups overcome the key issues described above, but still requires the patient’s presence at the hospital or clinic. Therefore, remote control programming is predominantly associated with benefits for the remote device clinic staff and patients at remote locations.

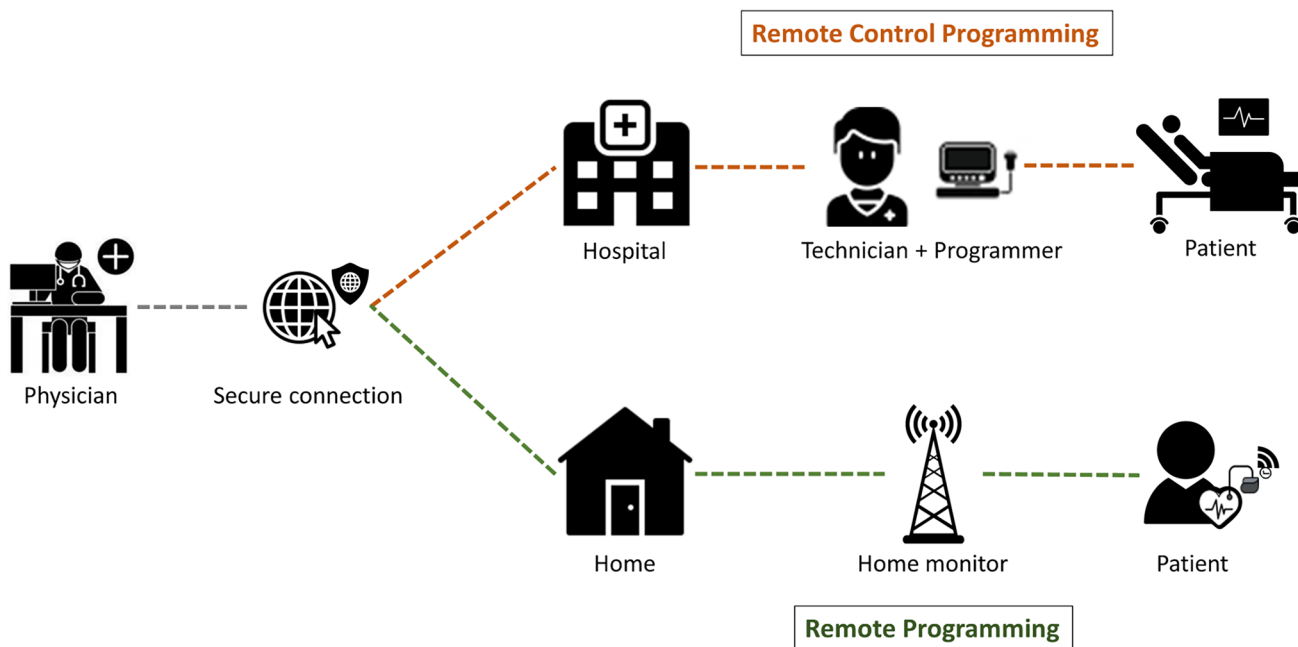


Fig. 5 Remote programming setups. Schematic presentation of the difference between remote control programming and true remote programming. In remote control programming, the patient has to present to a healthcare facility where a connection between the CIED and the programmer is initiated by a member of the device clinic team.

Using a secure connection, the physician can perform a remote device interrogation and reprogramming using the local programmer. In true remote programming, the physician would reprogram the CIED using the patient home monitor allowing the patient to stay at home

Conclusions

RM has proven its clinical value over time. RM should be considered standard of care. The clinical benefits of RM, such as early detection of actionable events and more efficient use of healthcare resources, can be maximized by using continuous RM and evolving towards an alert-based RM model. Given the progressively increasing workload there is an urgent need of adapted healthcare strategies to maintain the cost-effectiveness of RM and that allow device clinics to prepare themselves for the future. These strategies should aim for optimized RM device clinic staffing with sufficient support by administrative and non-clinical staff, appropriate reimbursement models, and universal data processing that allow development of standard operating protocols and workflows.

Declarations

Conflict of Interest SRR: consultant to Lundbeck LLC, Theravance Biopharma, and Amneal Pharma related to neurogenic orthostatic hypotension; consultant to Servier Affaires Médicales, Regeneron, argenx BV, and Antag Pharma related to postural orthostatic tachycardia syndrome. Honoraria from Spire Learning and Medscape for developing CME materials on neurogenic orthostatic hypotension. DMSB Chair for a Phase 2 study of an irritable bowel syndrome medication for Arena Pharmaceuticals with compensation. Past-President of the American Autonomic Society without financial compensation. Bert Vandenberg declares 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.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Slotwiner D, Varma N, Akar JG, Annas G, Beardsall M, Fogel RI, et al. HRS Expert Consensus Statement on remote interrogation and monitoring for cardiovascular implantable electronic devices. *Heart rhythm off J Heart Rhythm Soc.* 2015;12(7):e69–100. <https://doi.org/10.1016/j.hrthm.2015.05.008>.
2. Akinyele B, Marine JE, Love C, Crawford TC, Chrispin J, Vlay SC, et al. Unregulated online sales of cardiac implantable electronic devices in the United States: a six-month assessment. *Heart Rhythm O2.* 2020;14:235–8. <https://doi.org/10.1016/j.hroo.2020.06.007>.
3. Varma N, Marrouche NF, Aguinaga L, Albert CM, Arbelo E, Choi JI, et al. HRS/EHRA/APHRS/LAHRs/ACC/AHA worldwide practice update for telehealth and arrhythmia monitoring during

and after a pandemic. *Heart rhythm Off J Heart Rhythm Soc.* 2020;17(9):e255–68. <https://doi.org/10.1016/j.hrthm.2020.06.010>.

4. Burri H, Senouf D. Remote monitoring and follow-up of pacemakers and implantable cardioverter defibrillators. *Europace.* 2009;11(6):701–9. <https://doi.org/10.1093/europace/eup110>.
5. Burri H. Remote follow-up and continuous remote monitoring, distinguished. *Europace.* 2013;15(Suppl 1):i14–6. <https://doi.org/10.1093/europace/eut071>.
- 6.●● Varma N, Love CJ, Michalski J, Epstein AE. Alert-Based ICD Follow-Up JACC: Clinical Electrophysiology. 2021;7(8):976–87. <https://doi.org/10.1016/j.jacep.2021.01.008>. **(This randomized clinical trial illustrates the feasibility and safety of a fully alert-based remote monitoring strategy.)**
- 7.● Hindricks G, Varma N, Kacet S, Lewalter T, Sogaard P, Guedon-Moreau L, et al. Daily remote monitoring of implantable cardioverter-defibrillators: insights from the pooled patient-level data from three randomized controlled trials (IN-TIME, ECOST, TRUST). *Eur Heart J.* 2017;38(22):1749–55. <https://doi.org/10.1093/eurheartj/ehx015>. **This meta-analysis shows the potential of remote monitoring to improve rsurvival, mainly by prevention of heart failure exacerbations.**
8. Hindricks G, Taborsky M, Glikson M, Heinrich U, Schumacher B, Katz A, et al. Implant-based multiparameter telemonitoring of patients with heart failure (IN-TIME): a randomised controlled trial. *Lancet.* 2014;384(9943):583–90. [https://doi.org/10.1016/S0140-6736\(14\)61176-4](https://doi.org/10.1016/S0140-6736(14)61176-4).
- 9.●● Parthiban N, Esterman A, Mahajan R, Twomey DJ, Pathak RK, Lau DH, et al. Remote monitoring of implantable cardioverter-defibrillators: a systematic review and meta-analysis of clinical outcomes. *J Am Coll Cardiol.* 2015;65(24):2591–600. <https://doi.org/10.1016/j.jacc.2015.04.029>. **This meta-analysis demonstrates that the survival benefit associated with remote monitoring is dependent on daily remote transmissions as these allow more rapid clinical event detection.**
10. Varma N, Epstein AE, Irimpen A, Schweikert R, Love C. Efficacy and safety of automatic remote monitoring for implantable cardioverter-defibrillator follow-up. *Circulation.* 2010;122(4):325–32. <https://doi.org/10.1161/circulationaha.110.937409>.
11. Guedon-Moreau L, Lacroix D, Sadoul N, Clementy J, Kouakam C, Hermida JS, et al. A randomized study of remote follow-up of implantable cardioverter defibrillators: safety and efficacy report of the ECOST trial. *Eur Heart J.* 2013;34(8):605–14. <https://doi.org/10.1093/eurheartj/ehs425>.
12. Saxon LA, Hayes DL, Gilliam FR, Heidenreich PA, Day J, Seth M, et al. Long-term outcome after ICD and CRT implantation and influence of remote device follow-up: the ALTITUDE survival study. *Circulation.* 2010;122(23):2359–67. <https://doi.org/10.1161/CIRCULATIONAHA.110.960633>.
13. Kurek A, Tajstra M, Gadula-Gacek E, Buchta P, Skrzypek M, Pyka L, et al. Impact of remote monitoring on long-term prognosis in heart failure patients in a real-world cohort: results from all-comers COMMIT-HF trial. *J Cardiovasc Electrophysiol.* 2017;28(4):425–31. <https://doi.org/10.1111/jce.13174>.
- 14.● Varma N, Piccini JP, Snell J, Fischer A, Dalal N, Mittal S. The relationship between level of adherence to automatic wireless remote monitoring and survival in pacemaker and defibrillator patients. *J Am Coll Cardiol.* 2015;65(24):2601–10. <https://doi.org/10.1016/j.jacc.2015.04.033>. **In this nationwide analysis on 29471 consecutive patients, the survival benefit associated with remote monitoring was related to patient adherence, but independent of device type.**
15. Mabo P, Victor F, Bazin P, Ahres S, Babuty D, Da Costa A, et al. A randomized trial of long-term remote monitoring

- of pacemaker recipients (the COMPAS trial). *Eur Heart J*. 2012;33(9):1105–11. <https://doi.org/10.1093/eurheartj/ehr419>.
16. Halimi F, Clementy J, Attuel P, Dessenne X, Amara W, Ot Investigators. Optimized post-operative surveillance of permanent pacemakers by home monitoring: the OEDIPE trial. *Europace*. 2008;10(12):1392–9. <https://doi.org/10.1093/europace/eun250>.
 17. Oliveira M, Fernandes M, Reis H, Primo J, Sanfins V, Silva V, et al. Remote versus in-office monitoring for implantable cardioverter defibrillators: results from a randomized pragmatic controlled study in Portugal. *Rev Port Cardiol*. 2022. <https://doi.org/10.1016/j.repc.2021.08.017>.
 18. Versteeg H, Timmermans I, Widdershoven J, Kimman GJ, Prevot S, Rauwolf T, et al. Effect of remote monitoring on patient-reported outcomes in European heart failure patients with an implantable cardioverter-defibrillator: primary results of the REMOTE-CIED randomized trial. *Europace*. 2019;21(9):1360–8. <https://doi.org/10.1093/europace/euz140>.
 19. Leppert F, Siebermair J, Wesemann U, Martens E, Sattler SM, Scholz S, et al. The INFLuence of Remote monitoring on Anxiety/depReession, quality of life, and Device acceptance in ICD patients: a prospective, randomized, controlled, single-center trial. *Clin Res Cardiol*. 2021;110(6):789–800. <https://doi.org/10.1007/s00392-020-01667-0>.
 20. Petersen HH, Larsen MC, Nielsen OW, Kensing F, Svendsen JH. Patient satisfaction and suggestions for improvement of remote ICD monitoring. *J Interv Card Electrophysiol*. 2012;34(3):317–24. <https://doi.org/10.1007/s10840-012-9675-4>.
 21. Ricci RP, Morichelli L, Quarta L, Sassi A, Porfili A, Laudadio MT, et al. Long-term patient acceptance of and satisfaction with implanted device remote monitoring. *Europace*. 2010;12(5):674–9. <https://doi.org/10.1093/europace/euq046>.
 22. Timmermans I, Meine M, Szendey I, Aring J, Romero Roldan J, van Erven L, et al. Remote monitoring of implantable cardioverter defibrillators: patient experiences and preferences for follow-up. *Pacing Clinical Electrophysiol*. 2019;42(2):120–9. <https://doi.org/10.1111/pace.13574>.
 23. Artico J, Zecchin M, Zorzin Fantasia A, Skerl G, Ortis B, Franco S, et al. Long-term patient satisfaction with implanted device remote monitoring: a comparison among different systems. *J Cardiovasc Med (Hagerstown)*. 2019;20(8):542–50. <https://doi.org/10.2459/JCM.0000000000000818>.
 24. Hwang YM, Kim JH. The first survey on patient needs for remote monitoring of cardiac implantable electronic device in South Korea. *Medicine (Baltimore)*. 2022;101(23):e29414. <https://doi.org/10.1097/MD.00000000000029414>.
 25. Heidbuchel H, Lioen P, Foulon S, Huybrechts W, Ector J, Willems R, et al. Potential role of remote monitoring for scheduled and unscheduled evaluations of patients with an implantable defibrillator. *Europace*. 2008;10(3):351–7. <https://doi.org/10.1093/europace/eun010>.
 26. Varma N, Pavri BB, Stambler B, Michalski J, Investigators T. Same-day discovery of implantable cardioverter defibrillator dysfunction in the TRUST remote monitoring trial: influence of contrasting messaging systems. *Europace*. 2013;15(5):697–703. <https://doi.org/10.1093/europace/eus410>.
 27. Varma N, Michalski J, Epstein AE, Schweikert R. Automatic remote monitoring of implantable cardioverter-defibrillator lead and generator performance. *Circulation: Arrhythmia and Electrophysiology*. 2010;3(5):428–36. <https://doi.org/10.1161/circep.110.951962>.
 28. Varma N. Remote monitoring for advisories: automatic early detection of silent lead failure. *Pacing and clinical electrophysiology : PACE*. 2009;32(4):525–7. <https://doi.org/10.1111/j.1540-8159.2009.02314.x>.
 29. Spencker S, Coban N, Koch L, Schirdewan A, Muller D. Potential role of home monitoring to reduce inappropriate shocks in implantable cardioverter-defibrillator patients due to lead failure. *Europace*. 2009;11(4):483–8. <https://doi.org/10.1093/europace/eun350>.
 30. Varma N, Epstein AE, Schweikert R, Michalski J, Love CJ, Investigators T. Role of automatic wireless remote monitoring immediately following ICD implant: the Lumos-T reduces routine office device follow-up study (TRUST) trial. *J Cardiovasc Electrophysiol*. 2016;27(3):321–6. <https://doi.org/10.1111/jce.12895>.
 31. Ricci RP, Morichelli L, D'Onofrio A, Calo L, Vaccari D, Zanotto G, et al. Effectiveness of remote monitoring of CIEDs in detection and treatment of clinical and device-related cardiovascular events in daily practice: the HomeGuide Registry. *Europace*. 2013;15(7):970–7. <https://doi.org/10.1093/europace/eus440>.
 32. Guedon-Moreau L, Kouakam C, Klug D, Marquie C, Brigadeau F, Boule S, et al. Decreased delivery of inappropriate shocks achieved by remote monitoring of ICD: a substudy of the ECOST trial. *J Cardiovasc Electrophysiol*. 2014;25(7):763–70. <https://doi.org/10.1111/jce.12405>.
 33. Ricci RP, Pignalberi C, Landolina M, Santini M, Lunati M, Boriani G, et al. Ventricular rate monitoring as a tool to predict and prevent atrial fibrillation-related inappropriate shocks in heart failure patients treated with cardiac resynchronisation therapy defibrillators. *Heart*. 2014;100(11):848–54. <https://doi.org/10.1136/heartjnl-2013-305259>.
 34. Varma N, Love CJ, Schweikert R, Moll P, Michalski J, Epstein AE, et al. Automatic remote monitoring utilizing daily transmissions: transmission reliability and implantable cardioverter defibrillator battery longevity in the TRUST trial. *Europace*. 2018;20(4):622–8. <https://doi.org/10.1093/europace/eux059>.
 35. Glikson M, Nielsen JC, Kronborg MB, Michowitz Y, Auricchio A, Barbash IM, et al. 2021 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy. *Eur Heart J*. 2021;42(35):3427–520. <https://doi.org/10.1093/eurheartj/ehab364>.
 36. Buck BH, Hill MD, Quinn FR, Butcher KS, Menon BK, Gulamhusein S, et al. Effect of implantable vs prolonged external electrocardiographic monitoring on atrial fibrillation detection in patients with ischemic stroke: the PER DIEM randomized clinical trial. *JAMA*. 2021;325(21):2160–8. <https://doi.org/10.1001/jama.2021.6128>.
 37. Jang JP, Lin HT, Chen YJ, Hsieh MH, Huang YC. Role of remote monitoring in detection of atrial arrhythmia, stroke reduction, and use of anticoagulation therapy- a systematic review and meta-analysis. *Circ J*. 2020;84(11):1922–30. <https://doi.org/10.1253/circj.CJ-20-0633>.
 38. Healey JS, Connolly SJ, Gold MR, Israel CW, Van Gelder IC, Capucci A, et al. Subclinical atrial fibrillation and the risk of stroke. *N Engl J Med*. 2012;366(2):120–9. <https://doi.org/10.1056/NEJMoa1105575>.
 39. Lopes RD, Alings M, Connolly SJ, Beresh H, Granger CB, Mazuecos JB, et al. Rationale and design of the apixaban for the reduction of thrombo-embolism in patients with device-detected sub-clinical atrial fibrillation (ARTESiA) trial. *Am Heart J*. 2017;189:137–45. <https://doi.org/10.1016/j.ahj.2017.04.008>.
 40. Watanabe E, Yamazaki F, Goto T, Asai T, Yamamoto T, Hirooka K, et al. (2020) Remote management of pacemaker patients with biennial in-clinic evaluation: continuous home monitoring in the Japanese at-home study: a randomized clinical trial. *Circ Arrhythm Electrophysiol*. 13(5) e007734-e <https://doi.org/10.1161/CIRCEP.119.007734>
 41. García-Fernández FJ, OscaAsensi J, Romero R, Fernández Lozano I, Larrazabal JM, Martínez Ferrer J, et al. Safety and efficiency of a common and simplified protocol for pacemaker and defibrillator surveillance based on remote monitoring

- only: a long-term randomized trial (RM-ALONE). *Eur Heart J*. 2019;40(23):1837–46. <https://doi.org/10.1093/eurheartj/ehz067>.
42. ● Chew DS, Piccini JP, Au F, Frazier-Mills CG, Michalski J, Varma N, et al. Alert-driven versus scheduled remote monitoring of implantable cardiac defibrillators: a cost-consequence analysis from the TRUST trial. *Heart rhythm*. 2022. <https://doi.org/10.1016/j.hrthm.2022.12.003>. **This cost-consequence analysis shows that atler-driven remote monitoring was economically attractive.**
 43. Heidbuchel H, Hindricks G, Broadhurst P, Van Erven L, Fernandez-Lozano I, Rivero-Ayerza M, et al. EuroEco (European Health Economic Trial on Home Monitoring in ICD Patients): a provider perspective in five European countries on costs and net financial impact of follow-up with or without remote monitoring. *Eur Heart J*. 2015;36(3):158–69. <https://doi.org/10.1093/eurheartj/ehu339>.
 44. Health QO. Remote monitoring of implantable cardioverter-defibrillators, cardiac resynchronization therapy and permanent pacemakers: a health technology assessment. *Ont Health Technol Assess Ser*. 2018;18(7):1–199.
 45. Ricci RP, Vicentini A, D'Onofrio A, Sagone A, Rovaris G, Padelletti L, et al. Economic analysis of remote monitoring of cardiac implantable electronic devices: results of the Health Economics Evaluation Registry for Remote Follow-up (TARIFF) study. *Heart Rhythm*. 2017;14(1):50–7. <https://doi.org/10.1016/j.hrthm.2016.09.008>.
 46. Chiu CSL, Timmermans I, Versteeg H, Zitron E, Mabo P, Pedersen SS, et al. Effect of remote monitoring on clinical outcomes in European heart failure patients with an implantable cardioverter-defibrillator: secondary results of the REMOTE-CIED randomized trial. *Europace*. 2022;24(2):256–67. <https://doi.org/10.1093/europace/euab221>.
 47. Boriani G, Da Costa A, Quesada A, Ricci RP, Favale S, Boscolo G, et al. Effects of remote monitoring on clinical outcomes and use of healthcare resources in heart failure patients with biventricular defibrillators: results of the MORE-CARE multicentre randomized controlled trial. *Eur J Heart Fail*. 2017;19(3):416–25. <https://doi.org/10.1002/ehfj.626>.
 48. Boehmer JP, Hariharan R, Devecchi FG, Smith AL, Molon G, Capucci A, et al. A multisensor algorithm predicts heart failure events in patients with implanted devices: results from the MultiSENSE study. *JACC Heart Fail*. 2017;5(3):216–25. <https://doi.org/10.1016/j.jchf.2016.12.011>.
 49. Wintrich J, Pavlicek V, Brachmann J, Bosch R, Butter C, Oswald H, et al. Remote monitoring with appropriate reaction to alerts was associated with improved outcomes in chronic heart failure: results from the OptiLink HF study. *Cir Arrhythm Electrophysiol*. 2021;14(1):e008693. <https://doi.org/10.1161/CIRCEP.120.008693>.
 50. Abraham WT, Adamson PB, Bourge RC, Aaron MF, Costanzo MR, Stevenson LW, et al. Wireless pulmonary artery haemodynamic monitoring in chronic heart failure: a randomised controlled trial. *Lancet*. 2011;377(9766):658–66. [https://doi.org/10.1016/S0140-6736\(11\)60101-3](https://doi.org/10.1016/S0140-6736(11)60101-3).
 51. Akar JG, Bao H, Jones P, Wang Y, Chaudhry SI, Varosy P, et al. Use of remote monitoring of newly implanted cardioverter-defibrillators: insights from the patient related determinants of ICD remote monitoring (PREDICT RM) study. *Circulation*. 2013;128(22):2372–83. <https://doi.org/10.1161/CIRCULATIONAHA.113.002481>.
 52. Mittal S, Piccini JP, Snell J, Prillinger JB, Dalal N, Varma N. Improved survival in patients enrolled promptly into remote monitoring following cardiac implantable electronic device implantation. *J Interv Card Electrophysiol*. 2016;46(2):129–36. <https://doi.org/10.1007/s10840-016-0112-y>.
 53. Harvey M, Seiler A. Challenges in managing a remote monitoring device clinic. *Heart Rhythm O2*. 2022;3(1):3–7. <https://doi.org/10.1016/j.hroo.2021.12.002>.
 54. Ryan P, McGrath C, Lawrie I, Fitzsimons C, O'Shea J, De BrUn J. Enhancing efficiency in a cardiac investigations department by increasing remote patient monitoring. *Int J Qual Health Care*. 2019;31(Supplement_1):29–34. <https://doi.org/10.1093/intqhc/mzz065>.
 55. Kelly SE, Campbell D, Duhn LJ, Giddens K, Gillis AM, AbdelWahab A, et al. Remote monitoring of cardiovascular implantable electronic devices in Canada: survey of patients and device health care professionals. *CJC Open*. 2021;3(4):391–9. <https://doi.org/10.1016/j.cjco.2020.11.010>.
 56. ● O'Shea CJ, Middeldorp ME, Hendriks JM, Brooks AG, Lau DH, Emami M, et al. Remote monitoring alert burden: an analysis of transmission in >26,000 patients. *JACC Clin Electrophysiol*. 2021;7(2):226–34. <https://doi.org/10.1016/j.jacep.2020.08.029>. **This retrospective analysis illustrates the increasing workload of remote monitoring, predominantly generated by implantable loop recorders.**
 57. Seiler A, Biundo E, Di Bacco M, Rosemas S, Nicolle E, Lanctin D, et al. Clinic time required for remote and in-person management of patients with cardiac devices: time and motion workflow evaluation. *JMIR Cardio*. 2021;5(2):e27720. <https://doi.org/10.2196/27720>.
 58. Otsuki S, Izumi D, Sakaguchi Y, Suzuki N, Hakamata T, Ikami Y, et al. Efficacy of antitachycardia pacing alert by remote monitoring of implantable cardioverter-defibrillators for out-of-hospital electrical storm. *Pacing Clinical Electrophysiol*. 2021;44(10):1675–82. <https://doi.org/10.1111/pace.14334>.
 59. Guedon-Moreau L, Finat L, Boule S, Wissocque L, Marquie C, Brigadeau F, et al. Validation of an organizational management model of remote implantable cardioverter-defibrillator monitoring alerts. *Circ Cardiovasc Qual Outcomes*. 2015;8(4):403–12. <https://doi.org/10.1161/CIRCOUTCOMES.114.001433>.
 60. Lau CP, Zhang S. Remote monitoring of cardiac implantable devices in the Asia-Pacific. *Europace*. 2013;15(Suppl 1):i65–8. <https://doi.org/10.1093/europace/eut081>.
 61. Rosenfeld LE, Patel AS, Ajmani VB, Holbrook RW, Brand TA. Compliance with remote monitoring of ICDS/CRTDS in a real-world population. *Pacing Clin Electrophysiol*. 2014;37(7):820–7. <https://doi.org/10.1111/pace.12358>.
 62. Diamond J, Varma N, Kramer DB. Making the most of cardiac device remote management: towards an actionable care model. *Circ Arrhythm electrophysiol*. 2021;14(3):e009497. <https://doi.org/10.1161/CIRCEP.120.009497>.
 63. Morimoto Y, Nishii N, Tsukuda S, Kawada S, Miyamoto M, Miyoshi A, et al. A low critical event rate despite a high abnormal event rate in patients with cardiac implantable electric devices followed up by remote monitoring. *Intern Med*. 2019;58(16):2333–40. <https://doi.org/10.2169/internalmedicine.1905-18>.
 64. Slotwiner DJ, Abraham RL, Al-Khatib SM, Anderson HV, Bunch TJ, Ferrara MG, et al. HRS White Paper on interoperability of data from cardiac implantable electronic devices (CIEDs). *Heart Rhythm*. 2019;16(9):e107–27. <https://doi.org/10.1016/j.hrthm.2019.05.002>.
 65. Dubner S, Auricchio A, Steinberg JS, Vardas P, Stone P, Brugada J, et al. ISHNE/EHRA expert consensus on remote monitoring of cardiovascular implantable electronic devices (CIEDs). *Europace*. 2012;14(2):278–93. <https://doi.org/10.1093/europace/eur303>.
 66. Mairesse GH, Braunschweig F, Klersy K, Cowie MR, Leyva F. Implementation and reimbursement of remote monitoring for cardiac implantable electronic devices in Europe: a survey from the health economics committee of the European Heart Rhythm Association. *Europace*. 2015;17(5):814–8. <https://doi.org/10.1093/europace/euu390>.
 67. Bautista-Mesa RJ, Lopez-Villegas A, Peiro S, Catalan-Mata-moros D, Robles-Musso E, Lopez-Liria R, et al. Long-term

- cost-utility analysis of remote monitoring of older patients with pacemakers: the PONIENTE study. *BMC Geriatr.* 2020;20(1):474. <https://doi.org/10.1186/s12877-020-01883-3>.
68. Burri H, Sticherling C, Wright D, Makino K, Smala A, Tilden D. Cost-consequence analysis of daily continuous remote monitoring of implantable cardiac defibrillator and resynchronization devices in the UK. *Europace* . 2013;15(11):1601–8. <https://doi.org/10.1093/europace/eut070>.
 69. Crossley GH, Boyle A, Vitense H, Chang Y, Mead RH. The CONNECT (clinical evaluation of remote notification to reduce time to clinical decision) trial. *J Am Coll Cardiol.* 2011;57(10):1181–9. <https://doi.org/10.1016/j.jacc.2010.12.012>.
 70. Varma N, Michalski J, Stambler B, Pavri BB, Investigators T. Superiority of automatic remote monitoring compared with in-person evaluation for scheduled ICD follow-up in the TRUST trial - testing execution of the recommendations. *Eur Heart J.* 2014;35(20):1345–52. <https://doi.org/10.1093/eurheartj/ehu066>.
 71. Hindricks G, Elsner C, Piorowski C, Taborsky M, Geller JC, Schumacher B, et al. Quarterly vs yearly clinical follow-up of remotely monitored recipients of prophylactic implantable cardioverter-defibrillators: results of the REFORM trial. *Eur Heart J.* 2014;35(2):98–105. <https://doi.org/10.1093/eurheartj/ehu207>.
 72. Alexander B, Baranchuk A. Remote device reprogramming: has its time come? *Circ Arrhythm electrophysiol.* 2020;13(10):e008949. <https://doi.org/10.1161/CIRCEP.120.008949>.
 73. Baranchuk A, Alexander B, Campbell D, Haseeb S, Redfearn D, Simpson C, et al. Pacemaker cybersecurity: local experience with a firmware upgrade. *Circulation.* 2018;138(12):1272–3. <https://doi.org/10.1161/CIRCULATIONAHA.118.035261>.
 - 74.● Ploux S, Strik M, Demoniere F, Rakotoarimanana D, Zemmoura A, Deplagne A, et al. (2022) Remote interrogation and reprogramming of cardiac implantable electronic devices using a custom multivendor solution. *Heart rhythm : the official journal of the Heart Rhythm Society* <https://doi.org/10.1016/j.hrthm.2022.12.015> **This study describes the feasibility and safety of remote interrogations and remote programming in clinical practice by using a custom multivendor solution.**
 75. Xiong S, Li J, Tong L, Hou J, Yang S, Qi L, et al. (2022) Real-time remote programming in patients carrying cardiac implantable electronic devices requiring emergent reprogramming. *Front Cardiovasc Med.* 9 871425. <https://doi.org/10.3389/fcvm.2022.871425>
 76. Kloosterman EM, Rosenbaum M, La Starza B, Wilcox J, Rosman J. Remote control of cardiac implantable electronic devices: exploring the new frontier-first clinical application of real-time remote-control management of cardiac devices before and after magnetic resonance imaging. *J Innov Card Rhythm Manag.* 2019;10(1):3477–84. <https://doi.org/10.19102/icrm.2019.100102>.
 77. Siddamsetti S, Shinn A, Gautam S. Remote programming of cardiac implantable electronic devices: a novel approach to program cardiac devices for magnetic resonance imaging. *J Cardiovasc Electrophysiol.* 2022;33(5):1005–9. <https://doi.org/10.1111/jce.15434>.

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