BMJ Open

Does remote patient monitoring reduce acute care use? A systematic review

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-040232
Article Type:	Original research
Date Submitted by the Author:	10-May-2020
Complete List of Authors:	Taylor, Monica ; University of Queensland, Centre for Online Health, Centre for Health Services Research Thomas, Emma; University of Queensland Centre for Online Health, Centre for Online Health, Centre for Health Services Research Snoswell, Centaine; University of Queensland Centre for Online Health, Centre for Health Services Research Smith, Anthony; The University of Queensland, Centre for Online Health, Centre for Health Services Research Caffery, Liam; The University of Queensland, Centre for Online Health, Centre for Health Services Research
Keywords:	Telemedicine < BIOTECHNOLOGY & BIOINFORMATICS, HEALTH SERVICES ADMINISTRATION & MANAGEMENT, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Does remote patient monitoring reduce acute care use? A systematic review

Ms Monica Taylor[1] – ORCiD 0000-0001-5333-2955
Dr Emma Thomas[1] – ORCiD 0000-0001-8415-0521
Dr Centaine L Snoswell[1] – ORCiD 0000-0002-4298-9369
Professor Anthony C Smith[1] – ORCiD 0000-0002-7756-5136
Associate Professor Liam J Caffery[1] – ORCiD 0000-0003-1899-7534

1. Centre for Online Health, Centre for Health Services Research, The University of Queensland, Brisbane, Australia.

Corresponding author:
Associate Professor Liam Caffery
Ground Floor, Building 33, Princess Alexandra Hospital
Woolloongabba QLD 4102
Australia
l.caffery@uq.edu.au

Word Count: 3791

What is the key question?
Does the use of remote patient monitoring reduce acute care (hospital admission, length of stay and emergency department presentations) use?
What is the bottom line?
Remote patient monitoring for patients with cardiovascular disease and / or COPD resulted in a reduced acute care use in nearly half of interventions and no change in the remaining interventions.
Why read on?
Previous studies of RPM and their impact on acute health services have largely focussed on heart failure populations and manual collection of biometric data. Remote monitoring technologies have improved to now include automatic data collection using implanted devices and the use of RPM for other disease conditions. We present a contemporary review of the effectiveness of RPM in the context of hospital admissions, length of stay and emergency department presentations.

Abstract

Objective: Chronic diseases are associated with increased unplanned acute hospital use. Remote patient monitoring (RPM) can detect disease exacerbations and facilitate proactive management, possibly reducing expensive acute hospital usage. Current evidence examining RPM and acute care use is mainly on heart failure and does not include automated invasive monitoring. The aim of this study is to determine if RPM reduces acute hospital use.

Methods: A systematic literature review of Pubmed, EMBASE and CINAHL electronic databases was undertaken for studies published 2015-2019 that reported RPM and effect on hospitalisations, length of stay, or emergency department presentations. All populations and disease conditions were included. Screening was conducted by two independent reviewers. Quality analysis was performed using the Joanna Briggs Institute checklist. Findings were stratified by outcome variable. Subgroup analysis was undertaken on disease condition and remote monitoring technology.

Results: From 1,463 identified records, 75 studies were included. Studies were medium to high quality. RPM for all disease conditions was reported to reduce admissions, length of stay, and emergency department presentations in 45%, 46%, and 43% of studies reporting each measure, respectively. Remaining studies largely reported no change. Three studies reported RPM increased acute care use. RPM of chronic obstructive pulmonary disease (COPD) was more effective at reducing emergency presentation than RPM of other disease conditions. Similarly, invasive monitoring of cardiovascular disease was more effective at reducing hospital admissions versus other disease conditions and non-invasive monitoring.

Conclusion: RPM can reduce acute hospital use for cardiovascular disease and COPD patients. However, effectiveness varies within and between populations. RPM's effect on other disease conditions is inconclusive due to limited studies. Further analysis is required to understand underlying mechanisms causing such variation in RPM interventions. Findings from this review should be considered alongside other benefits of RPM, including increased quality of life for patients.

Generic keywords: telehealth; telemedicine; telecare; remote monitoring; telemonitoring; in-home monitoring; hospitalization; length of stay
ScholarOne keywords: Telemedicine, Health Services Administration & Management, International health services

Strengths and limitations

- This systematic review was not limited by disease condition and gives an overall picture on the effect of remote patient monitoring on acute care hospital use.
- We have included sub-analyses and new evidence, particularly for COPD patients and monitoring using implanted devices.
- Due to heterogeneity of included studies we were unable to perform a meta-analysis.

INTRODUCTION

Many people find it challenging to self-manage complex and co-morbid conditions and identify warning signs of exacerbation. While healthcare providers often only become aware of a decline in an individual's condition when symptoms have become severe enough to require escalation to acute care. This scenario may be avoided by using remote patient monitoring (RPM).

RPM or telemonitoring refers to the recording and transmission of patient biometrics, vital signs, and/or disease-related data to a healthcare provider using information and communications technology. RPM data are disease-specific and commonly include measurements like blood pressure, weight, heart rate, respiration rate, pulse oximetry, spirometry, temperature, blood glucose levels or specific symptoms.[1] Data can be collected automatically (e.g. by an implanted or wearable devices) or manually collected by the patient using peripheral devices and a transmission hub. RPM interventions for cardiovascular disease (CVD) can be either invasive or non-invasive. Invasive interventions involve direct measurement of biometric data, such as heart rate and pulmonary artery pressures, by an implanted device which is then transmitted to the healthcare provider. Non-invasive interventions involve the transmission of data, such as bodyweight, blood pressure, or pulse oximetry.[2] Review of transmitted data may be active, which occurs when a remote healthcare provider regularly reviews patient data. Alternatively, it may be passive when the healthcare provider is only alerted if data readings reach a pre-determined clinical threshold. Interventions resulting from an abnormal data reading or data indicative of a decline in condition may include telephone support, videoconsultation, or home visits.

Chronic diseases are associated with high rates of unplanned acute hospital use, even more so when the patient has co-morbid conditions.[3] This represents a substantial cost to the health system. For example, in Australia there are more than 748,000 potentially avoidable hospitalizations per year, of which nearly half (46%) were due to chronic conditions such as congestive cardiac failure, diabetes complications, chronic obstructive pulmonary disease (COPD) and angina.[4]

Early detection and proactive management of chronic disease exacerbations may result in decreased costly acute hospital use. Existing research shows that for RPM to be cost effective it needs to reduce acute hospital use.[5] There have been a number of disease specific reviews (such as heart failure) that have reported effect of RPM on acute hospital use, however this is often a secondary outcome.[2, 6-8] These reviews were largely published more than five years ago. Hence, there is limited evidence for the effect of RPM using newer technologies such as implanted devices and for other disease conditions.[9] The aim of this study is to provide a contemporary evidence synthesis that will determine if RPM can reduce acute hospital use.

METHODS

In order to achieve the aims of this study we conducted a systematic review of publications from the last five years (2015-2019). The protocol for our review was registered (registration number: CRD42020142523) with the Prospective Register of Systematic Reviews (PROSPERO).[10]

Search strategy

To identify relevant articles we conducted searches of three electronic databases: PubMed (MEDLINE)[1966-2019], EMBASE (OvidSP)[1974-2019], and CINAHL (EBSCOHost)[1982-2019]. Boolean search terms (Box 1) were developed with the assistance of a university librarian and used a combination of medical subject headings (MeSH) and keywords related to remote monitoring, telemedicine, and acute care utilization. Searches were conducted in July 2019.

("Hospitalization"[Mesh] OR "length of stay"[All Fields] OR ("hospitalization"[All Fields] OR "hospitalization"[MeSH Terms] OR "hospitalization"[All Fields]) OR admission[All Fields] OR presentation[All Fields])

AND

("Remote monitoring"[All Fields] OR "Remote patient monitoring"[All Fields] OR (Inhome[All Fields] AND monitoring[All Fields]) OR "In-home monitoring"[All Fields] OR "Home telehealth"[All Fields] OR Telemonitoring[All Fields] OR Telecare[All Fields])

AND

((Case Reports[ptyp] OR Clinical Study[ptyp] OR Clinical Trial[ptyp] OR Clinical Trial, Phase I[ptyp] OR Clinical Trial, Phase II[ptyp] OR Clinical Trial, Phase III[ptyp] OR Clinical Trial, Phase IV[ptyp] OR Comparative Study[ptyp] OR Controlled Clinical Trial[ptyp] OR Evaluation Studies[ptyp] OR Introductory Journal Article[ptyp] OR Journal Article[ptyp] OR Meta-Analysis[ptyp] OR Multicenter Study[ptyp] OR Observational Study[ptyp] OR Randomized Controlled Trial[ptyp] OR Validation Studies[ptyp])
AND English[lang])

Box 1 Example search strategy (PubMed)

Inclusion/exclusion criteria

We included primary, empirical studies that compared acute hospital use by patients undergoing RPM with those not remotely monitored, or studies that compared acute hospital use pre- and post- RPM. Acute hospital use for the purpose of this review is defined as hospital admissions (including readmissions), length of stay, and emergency department (ED) presentations. Patients could be monitored for any disease condition as long as the monitored data was sent to a clinician for review (i.e. self-monitoring was excluded). Only English language articles where the full-text was available were included.

Interventions that did not involve a disease condition (e.g. those with a focus on monitoring physical activity) were excluded. Studies that used simulated or modelled data were excluded, as were reviews, non-experimental studies, conference abstracts, and commentaries.

Selection

Titles and abstracts were screened by two researchers (MT, MB) and where necessary the full text was used to determine eligibility. A third researcher (CS, ET, or LC) decided on inclusion when consensus was not reached.

Data extraction

Data was extracted from the full text of the articles and recorded on a data extraction form. A description of data extraction variables can be found in Table 1. One author (MT) extracted the data and a second author (ET) validated the accuracy by checking a 20% random selection of the data.

Table 1 Extracted variables

Variable	Description
First Author	Surname of the first author of the publication
Year	Year of publication
Country	Country where research was conducted
Study Type	Study design as cohort, RCT, quasi-experimental, or case-control
Patient Group	Medical condition of study participants
Comorbidities	Whether or not the authors mentioned participants having comorbidities
Data being monitored	Patient vitals measured using remote monitoring (e.g. BP, heart rate, etc.)
Trial length	Length of time a patient was remotely monitored (number of months)
Sample size	Number of participants in the research, listed by intervention and control groups
Mean age	The average or mean age of the intervention and control groups as reported by authors
Gender split	Percentage of male and female participants in the study
RPM Device	Device used for remote monitoring (e.g. tablet, dedicated RM unit, phone, etc.)
Data collection	Whether biometric data was collected manually or automatically
Data review	Whether biometric data was reviewed by clinical staff passively (e.g. there was an automated alert system) or actively (e.g. nurse checks dashboard each day)
Supplementary support mode	If support from clinical staff beyond event management or routine visits occurred, what was the mode of contact used
Outcome type	Whether the outcome reported was for all cause, condition-specific, both, or not specified
Outcome findings	Results of the investigation (significant or not significant increase or decrease in acute care use and effect size where available)
Summary	Overall summary of whether RM increased, decreased, or had no significant effect on acute care use in the study

Quality assessment

Quality of the included studies was assessed using The Joanna Briggs Institute (JBI) critical appraisal checklists.[11] This suite of checklists has individual templates based on study design. Specific checklists have different numbers of questions. The appropriate checklist was chosen using an algorithm for classifying study design. [12] To allow comparison across study design, the number of "yes" scores was converted to a proportion of the total number of questions.

Two researchers (MT, ET) completed quality assessment on each article and scores were compared and consensus was reached via discussion. When a publication reported outcomes both related and not related to acute case use, the quality assessment score was based on the measurement of the acute care use outcomes specifically. No articles were excluded from this review based on their quality score.

Analysis

Findings from included article were stratified by acute care use as admissions, ED presentations or length of stay. Findings were categorised by the author's conclusion on increased, decreased, or no change on acute hospital use. Changes in use that were not statistically significant were categorised as no change. Subgroup analysis was undertaken on disease condition and technology category permutations (i.e. invasive versus non-invasive).

Due to the heterogeneity in population groups, intervention designs and outcome measures findings were synthesized narratively. Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[13]

RESULTS

Study selection

Seventy-five articles were included in this review. The results of each stage of search and selection process are shown in the PRISMA diagram (Figure 1).

[INSERT FIGURE 1]

Study characteristics

Included studies were primarily conducted in Europe (n = 42, 56%), followed by the United States (n=25, 33%). Most studies were randomized controlled trials (RCTs) (n=38, 51%) or cohort studies (n=30, 40%), with six quasi-experimental studies (8%) and one case-control (<1%).

The sample size of patients ranged from 25 [14] to 92,566 [15] with the majority of included studies (n=59, 79%) having a sample size of greater than 100 participants (intervention and control arms combined). Follow-up time was longer than six months in the majority of studies (n=49, 65%), however, 15% (n=11) had a follow-up time of three months or less. Twenty-nine studies (39%) included >70% male participants. Gender bias was commonly observed in many CVD trials despite similar numbers of deaths across both genders.[16, 17] All interventions, except one study on infants with heart disease, were targeted at adults. Acute hospital use was reported for all causes (n=17, 23%), only the remotely monitored condition (n=18, 24%), both the all cause and the disease-specific condition (n=19, 25%), or was not specified (n=21, 28%).

Characteristics of all included studies are summarized in Supplementary Table 1.

Intervention characteristics

Disease conditions

The patient populations in the included studies were mostly people with CVD (n=44, 59%), COPD (n=17, 23%) or co-morbid CVD and COPD (n=3, 4%). Of these, invasive monitoring was used for 15 studies and non-invasive monitoring was used in 25 studies. Remaining studies (n=11, 15%) had varying study populations including nursing home residents, patients with schizophrenia, and individuals on home ventilation.

Remote monitoring processes

The most common biometrics that were remotely monitored were heart rate (n=43, 57%), blood pressure (n=35, 47%), oxygen saturation (n=34, 45%) and weight (n=33, 44%). Cardiac invasive electronic devices (CIEDs) (n=15, 20%) can enable automated transmission of data, monitor heart rhythm, alert if an arrhythmic episode occurs and check the device function.

A comparison of data being monitored in each study can be seen in Supplementary Table 2.

The non-invasive interventions (n=60, 80%) required manual data collection performed by the patient or support person. Clinical review of biometrics was evenly split between those that had passive review (i.e. automated alert) and those that had active data review (e.g. clinician logging into system to review patient data daily). Typically, manual data collection was actively reviewed by a nurse or other clinician once per day.

In all studies out-of-range biometrics triggered clinical communication. Some interventions involved supplementary services from staff, such as assisting with education and health literacy. Modes of communication with patients included telephone (n=33, 44%), videoconference (n=13, 17%), and asynchronous methods such as SMS or email (n=9, 12%).

Technology

The technology for RPM was either a dedicated unit or hub (n=28, 37%); CIEDs including implantable cardioverter-defibrillator (ICDs), cardiac resynchronization therapy (CRT) including those with defibrillators (CRT-Ds), and pacemakers (n=19, 25%); tablet computers application (n=12, 16%); or telephone or smartphone app (n=7, 9%); websites (n=3, 4%); or other technologies such as an electronic health diary, inhaler, or medication device (n=6, 8%). Thirty-six studies explicitly stated the patient used peripheral devices such as weight scales, pulse oximeters, and thermometers.

Effect of remote monitoring on acute care use

RPM for all disease conditions was reported to have reduced admissions, length of stay and ED presentations in 45%, 46% and 43% of studies respectively for studies that reported each measure of acute care use. The remaining studies largely reported no change in acute care use for remotely monitored patients. A very small number of studies reported RPM increased acute care use (Figure 2, Figure 3, Figure 4).

[Insert Figure 2]

[Insert Figure 3]

[Insert Figure 4]

CVD invasive

CVD using invasive monitoring appears to be most effective at reducing hospitalizations (Figure 2). Six RCTs have been conducted.[18-23] Of these, only one[19] demonstrated a significant reduction in acute care use with a reduction in length of hospital stays by 2.5 days (RPM = 10.3 ± 8.1 days, median: 8.0 days vs. non-monitored group = 17.5 ± 19.9 days, median 10.5 days, p = 0.027). All remaining RCTs (n=5; 83%) showed no significant effect. Of the seven cohort studies conducted with invasive monitoring, five (71%) showed a significant reduction in hospital use. Two of these[15, 24] had very large sample sizes with matched controls (n=37,742 and 92,566 respectively). In fact, Piccini et al. [15], had a larger sample size (n=92,566) than all the other CVD invasive populations combined (n=49,113). Both Piccini et al. [15] and Akar et al. [24] reported an 18% lower risk of all-cause hospitalization in the RPM groups with both studies reporting identical adjusted hazard ratios of 0.82 (95% CI: 0.80 – 0.84; p-value: <0.001). Piccini et al. [15] also reported a shorter mean length of hospital stay of approximately three days (5.3 days vs. 8.1 days; P<0.001). These reductions were preserved for all implanted device types (pacemakers, ICDs and CRT) but were maximal in CRT participants. By contrast Ladapo et al.[25] reported the most pronounced benefits of hospital use in patients with ICDs.

CVD non-invasive

All RCTs investigating the impact of non-invasive RPM were for heart failure populations. Findings from these studies have been mixed with nine trials (60%) reporting no difference and six trials (40%) reporting a reduction in acute hospital use. The largest study reported the RPM group spent approximately two days less in hospital compared to control participants (RPM group = mean 3.8 days per year, 95% CI: 3.5–4.1 vs 5.6 days per year 95% CI: 5·2–6·0).[26] However, similarly large RCTs reported no change in the number of hospitalizations or length of stay.[27, 28] Studies varied in regard to the precise population investigated, the duration of RPM, the type of devices used, and the intensity and timing of the interaction. Koehler et al. provided the first structured RPM intervention that used a holistic approach including multiple healthcare providers (e.g. cardiologist, GP, nurse) and tailored support using a predefined algorithm.[26]

COPD

RPM of COPD appears to be most effective at reducing ED presentations (Figure 4). Of the 12 RCTs investigating RPM in COPD populations, six trials (50%) showed no significant difference in hospital use between the intervention and control groups and 30% reported a reduction in hospital use. Two reported an increase in hospital admissions in the RPM group;[29,30] Udsen et al.[30] had the largest sample size (n=578/647 intervention/control) of the trials. Across the RCTs, COPD-related hospitalizations differed from a mean difference of ten fewer admissions in the intervention group of Sink et al.[31] over eight months (absolute risk reduction=11.6%; RPM = 6 hospitalizations vs. non-monitored = 16 hospitalizations) to a slight increase in admissions over a six month period (RPM admissions = 0.63 vs. 0.32 in non-monitored mean difference: 0.32, p-value: 0.026). [29] The majority of cohort studies (n=6, 75%) reported a reduction in at least one measure of acute hospital use. Of these the largest sample size (n=651/7047 intervention/control) and over a 12-month period reported a lower proportion of patients hospitalized due to all-causes (−15.16%, p < 0.0001), and

COPD-specific admissions (−20.27%, p < 0.0001). [32] On average, people in the RPM group spent 3.1 (p < 0.0001) and 2.07 (p < 0.001) fewer days in hospital due to all causes and COPD, respectively, than the control group.

Other conditions

The current RPM literature to date is dominated by adult CVD and COPD populations. It is worth noting that beneficial effects of RPM have been observed in some other conditions. Notably, one study demonstrated a significant reduction in hospital admission among infants with single ventricular heart disease (relative risk of hospital use in the control group: 2.19, 95% CI: 1.16-4.12, P = .016). [33] Reductions in hospital use were also seen in RPM groups with multiple chronic conditions ;[34] mental health; [35,36] and patients with home-ventilated neuromuscular conditions.[37]

Study quality

The overall quality of studies as assessed by the JBI critical appraisal checklists was medium to high (Figure 5). The quality of RCTs was most often compromised by participant outcomes being assessed by someone who was not blinded to the control or intervention group. However, it can be challenging to blind an assessor or participant in this type of intervention. In cohort studies, the quality was compromised by incomplete follow. Only one third of the studies had clearly done so, while the remaining two thirds either did not address incomplete follow up or it was unclear.

[Insert Figure 5]

DISCUSSION

This systematic review found around half of 75 included studies reported RPM decreased hospital admissions and around half reported no change. A smaller number of studies reported the effect of RPM on length of stay (n=41) and ED presentations (n=28). With around half reporting a decrease and half reported no change for both of these measures of acute hospital use. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Similarly, invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease condition and non-invasive monitoring. Only three studies reported higher acute hospital use resulting from RPM.[29, 30, 38] Around 80% of included studies were for CVD, COPD or co-morbid CVD and COPD. RPM for lesser studied populations including mental health and neuromuscular conditions, appears feasible but findings on acute hospital use is inconclusive due to the limited number of studies. Study quality as appraised by the JBI critical appraisal checklist was considered medium to high.

A strength of this study when compared to other reviews was the inclusion of all disease conditions, monitoring types and study designs. The broad inclusion categories has allowed analysis of RPM on disease conditions beyond those published on heart failure, previously excluded studies (e.g. cohort studies), and comparison of effectiveness of different RPM interventions. Whilst RCTs are considered the gold-standard experimental design, restricting to RCTs excludes large scale cohort studies, which can provide both strong evidence and are more applicable to real-world settings. For example, the Parthiban et al. [39] meta-analysis is, to the best of our knowledge, the only review that reports the impact on hospital admissions resulting from invasive cardiac monitoring. This study found no significant reduction in admissions. While findings from a large scale cohort study (n=34,259/58,307 intervention/control) by Piccini et al.[15] were that invasive cardiac monitoring significantly reduced both all-cause hospitalizations and the resultant length of stay

The one previous review of RPM for COPD populations included six primary studies (both RCTs and other study designs) of which four reported reduction in hospital admissions.[9] Our review included 17 studies on RPM of COPD and co-morbid COPD populations. Our findings were consistent when comparing the effect on hospital admissions. However, in addition we found a reduction in ED presentations in around half of the studies. Two of the three studies that reported RPM resulted in increased acute care use were in COPD population. This increase may explained by the perception that predicting COPD exacerbations based on variations in spirometry and other physiological measures continues to be a challenge resulting in high rates of false positive warnings in this cohort.[32]

Clinical outcomes for patients on remote monitoring has been more effective for sub-populations when compared to the whole of population. The largest study to date, [15] reported that RPM was associated with reductions in all-cause hospitalization. While this association held across all implanted devices, it was most evident for cardiac resynchronization therapy patients, suggesting that sicker patients are the most likely to benefit. Furthermore, the greater effectiveness of invasive RPM may result from the continuous generation of biometric measurements. Whereas, non-invasive monitoring produces intermittent measurements. This review has also demonstrated that the way remote monitoring services are implemented are highly variable and intervention characteristics could be a determinant of outcomes. For example, patients using smartphone apps were shown to have better compliance to monitoring than those using a web page.[40]

RPM interventions are complex and require careful patient selection along with appropriate technology that accurately alerts healthcare staff and results in a timely response. Additionally, how RPM might improve a patient's health literacy and self-efficacy to manage their condition is likely to be highly important.[41] Supportive of this theory is one author who speculated this was due to participants becoming dependant on the RPM systems and telemonitoring nurse rather than developing the appropriate skills to self-manage. [42] A patient-centred approach that enables seamless interaction between patients and the healthcare system is likely to influence RPM success. This is demonstrated well by the comprehensive approach Koehler et al. [26] took by involving multiple healthcare providers (e.g. cardiologist, GP, nurse) and using an algorithm to tailor support to participants resulting in positive results for people with heart failure.

Many studies reported that RPM increased quality of life, improved the timeliness of atrial fibrillation detection and improved communication.[2, 8, 28, 43] Focusing on effect of acute care use, may result in overlooking ancillary benefits of RPM.

There appears to be a lack of studies for some highly prevalent chronic conditions such as diabetes. This may be explained by the fact that exacerbation of diabetes is less likely to result in acute hospital use relative to CVD or COPD; and therefore studies on the effect of remote monitoring of diabetes do not use acute hospital use as an outcome measure.

Findings of this review should be interpreted in light of some limitations. First, publication bias is possible with selective reporting of studies with findings of reduced acute hospital use. The included studies were highly heterogeneous in terms of patient groups (e.g. co-morbidities), intervention (e.g. inclusion of educational component, invasive versus non-invasive monitoring, active versus passive review) and study differences (e.g. all-cause *versus* disease-specific acute hospital use). This makes generalizability of findings difficult. Due to heterogeneity and inability to perform a meta-analysis we used proportion of studies reporting a decrease in acute hospital use as a measure of comparative effectiveness. Differences in the control population may also lead to very different rates of admissions and influence whether or not a significant effect is found. For example, Boriani et al. [44] compared two trials found that one year mortality in the control-arm of each trial differed by nearly

a factor of two. Finally, a study that uses patient self-reported acute hospital use may be less rigorous than those that used a retrospective approach supported by activity data, due to patient recall bias. [45]

Further investigation is needed to identify sub-populations and intervention characteristic that will enhance the effectiveness of remote monitoring. Policy makers and funders also need to understand if remote monitoring is cost effective. It is important for implementation of RPM interventions to consider costs from a system perspective. It would be wrong to assume that reducing admissions reduces costs, as there is potential of increasing collateral health system usage (e.g. to outpatient care). Economic analysis is also needed to consider the cost of implementing and operating RPM interventions as opposed to only comparing the direct cost of acute care use.[46]

Conclusion

This review has shown that RPM of CVD and COPD can reduce hospital admissions, length of stay, and emergency presentation in around half of interventions and results in no change in acute care usage in the remaining. Increased acute care use was rarely reported. The effect of RPM for other disease condition is inconclusive due to the limited number of studies in these areas. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease condition and non-invasive monitoring. Further analysis is required to understand the underlying mechanisms causing such variation in RPM studies. Findings from this review should be considered alongside other benefits of RPM including increased quality of life and autonomy for patients.

Acknowledgements

The authors would like to thank Julie Hansen, Senior Librarian from UQ Library for her assistance in developing the search strategy for this systematic review. They would also like to thank Ms Maryama Bihi for her assistance in screening titles and abstracts.

Conflict of Interest Statement

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Funding

This research is conducted for the NHMRC Partnership Centre for Health System Sustainability (Grant ID #: 9100002) administered by the Australian Institute of Health Innovation, Macquarie University. Along with the NHMRC, the funding partners in this research collaboration are: The Bupa

Health Foundation; NSW Ministry of Health; Department of Health, WA; and The University of Notre Dame Australia. Their generous support is gratefully acknowledged.

While the NHMRC, The Bupa Health Foundation, NSW Ministry of Health, Department of Health, WA and The University of Notre Dame Australia, have provided in-kind and financial support for this research, they have not reviewed the content and are not responsible for any injury, loss or damage however arising from the use of, or reliance on, the information provided herein. The published material is solely the responsibility of the authors and does not reflect the views of the NHMRC or its funding partners.

Author Statement

This research was conceptualised by LC. MT, ET, CS, AS and LC contributed to the study design. Searches and data extraction carried out by MT and ET under guidance from CS and LC. Data analysis was performed by MT, ET, and LC. Manuscript was drafted by MT, ET, and LC. Critical review of manuscript was undertaken by all authors. All authors approved the final manuscript.

Patient Involvement Statement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

References

1. Malasinghe LP, Ramzan N and Dahal K. Remote patient monitoring: a comprehensive study. *Journal of Ambient Intelligence and Humanized Computing*. 2019; 10: 57-76.
2. Inglis SC, Clark RA, McAlister FA, Stewart S and Cleland JG. Which components of heart failure programmes are effective? A systematic review and meta-analysis of the outcomes of structured telephone support or telemonitoring as the primary component of chronic heart failure management in 8323 patients: abridged Cochrane review. *European journal of heart failure*. 2011; 13: 1028-40.
3. Hernandez C, Jansa M, Vidal M, Nunez M, Bertran M, Garcia-Aymerich J and Roca J. The burden of chronic disorders on hospital admissions prompts the need for new modalities of care: a cross-sectional analysis in a tertiary hospital. *QJM: An International Journal of Medicine*. 2009; 102: 193-202.
4. Australian Institute of Health and Welfare.AIHW Potentially preventable hospitalizations in Australia by small geographic areas. 2019 Available at: https://www.aihw.gov.au/reports/primary-health-care/potentially-preventable-hospitalisations/contents/overview (Accessed: 22 April 2020)
5. Seto E. Cost comparison between telemonitoring and usual care of heart failure: a systematic review. *Telemedicine and e-Health*. 2008; 14: 679-86.
6. Bashi N, Karunanithi M, Fatehi F, Ding H and Walters D. Remote monitoring of patients with heart failure: an overview of systematic reviews. *Journal of medical Internet research*. 2017; 19: e18.
7. Conway A, Inglis SC, Chang AM, Horton-Breshears M, Cleland JG and Clark RA. Not all systematic reviews are systematic: a meta-review of the quality of systematic reviews for non-invasive remote monitoring in heart failure. *Journal of telemedicine and telecare*. 2013; 19: 326-37.
8. Purcell R, McInnes S and Halcomb EJ. Telemonitoring can assist in managing cardiovascular disease in primary care: a systematic review of systematic reviews. *BMC family practice*. 2014; 15: 43.
9. Bolton CE, Waters CS, Peirce S and Elwyn G. Insufficient evidence of benefit: a systematic review of home telemonitoring for COPD. *Journal of evaluation in clinical practice*. 2011; 17: 1216-22.
10. PROSPERO International prospective register of systematic review.National Institute for Health Research, The impact of remote patient monitoring on acute hospital use 2020 Available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=142523 (Accessed: 22 April 2020)
11. Joanna Briggs Institute.University of Adelaide Critical Appraisal Tools 2020 Available at: https://joannabriggs.org/ebp/critical_appraisal_tools (Accessed: 22 April 2020)
12. The National Institute for Health and Care Excellence (NICE) and the Scottish Intercollegiate Guidelines Network (SIGN). Algorithm for classifying study design for questions of effectiveness Unknown year Available at: https://www.sign.ac.uk/assets/study_design.pdf (Accessed:
13. PRISMA. Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2015 Available at: http://www.prisma-statement.org/ (Accessed: 22 April 2020)
14. Hale TM, Jethwani K, Kandola MS, Saldana F and Kvedar JC. A Remote Medication Monitoring System for Chronic Heart Failure Patients to Reduce Readmissions: A Two-Arm Randomized Pilot Study. *Journal of medical Internet research*. 2016; 18: e91.
15. Piccini JP, Mittal S, Snell J, Prillinger JB, Dalal N and Varma N. Impact of remote monitoring on clinical events and associated health care utilization: A nationwide assessment. *Heart Rhythm*. 2016; 13: 2279-86.
16. Mehran R, Vogel B, Ortega R, Cooney R and Horton R. The Lancet Commission on women and cardiovascular disease: time for a shift in women's health. *The Lancet*. 2019; 393: 967-8.
17. The Lancet. Cardiology's problem women. *The Lancet*. 2019; 393: 959.

18. Amara W, Montagnier C, Cheggour S, Boursier M, Gully C, Barnay C, Georger F, Deplagne A, Fromentin S, Mlotek M, Lazarus A and Taieb J. Early Detection and Treatment of Atrial Arrhythmias Alleviates the Arrhythmic Burden in Paced Patients: The SETAM Study. *Pacing and clinical electrophysiology : PACE*. 2017; 40: 527-36.
19. Bulava A, Ošmera O, Šnorek M, Novotný A and Dušek L. Cost analysis of telemedicine monitoring of patients with implantable cardioverter-defibrillators in the Czech Republic. *Cor et Vasa*. 2016; 58: e293-e302.
20. Geller JC, Lewalter T, Bruun NE, Taborsky M, Bode F, Nielsen JC, Stellbrink C, Schon S, Muhling H, Oswald H, Reif S, Kaab S, Illes P, Proff J, Dagres N and Hindricks G. Implant-based multi-parameter telemonitoring of patients with heart failure and a defibrillator with vs. without cardiac resynchronization therapy option: a subanalysis of the IN-TIME trial. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2019.
21. Hansen C, Loges C, Seidl K, Eberhardt F, Troster H, Petrov K, Gronefeld G, Bramlage P, Birkenhauer F and Weiss C. INvestigation on Routine Follow-up in CONgestive HearT FAilure Patients with Remotely Monitored Implanted Cardioverter Defibrillators SysTems (InContact). *BMC cardiovascular disorders*. 2018; 18: 131.
22. Heidbuchel H, Hindricks G, Broadhurst P, Van Erven L, Fernandez-Lozano I, Rivero-Ayerza M, Malinowski K, Marek A, Romero Garrido RF, Loscher S, Beeton I, Garcia E, Cross S, Vijgen J, Koivisto UM, Peinado R, Smala A and Annemans L. 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. *European heart journal*. 2015; 36: 158-69.
23. Luthje L, Vollmann D, Seegers J, Sohns C, Hasenfuss G and Zabel M. A randomized study of remote monitoring and fluid monitoring for the management of patients with implanted cardiac arrhythmia devices. *Europace*. 2015; 17: 1276-81.
24. Akar JG, Bao H, Jones PW, Wang Y, Varosy PD, Masoudi FA, Stein KM, Saxon LA, Normand SL and Curtis JP. Use of Remote Monitoring Is Associated With Lower Risk of Adverse Outcomes Among Patients With Implanted Cardiac Defibrillators. *Circulation Arrhythmia and electrophysiology*. 2015; 8: 1173-80.
25. Ladapo JA, Turakhia MP, Ryan MP, Mollenkopf SA and Reynolds MR. Health Care Utilization and Expenditures Associated With Remote Monitoring in Patients With Implantable Cardiac Devices. *The American journal of cardiology*. 2016; 117: 1455-62.
26. Koehler F, Koehler K, Deckwart O, Prescher S, Wegscheider K, Kirwan BA, Winkler S, Vettorazzi E, Bruch L, Oeff M, Zugck C, Doerr G, Naegele H, Störk S, Butter C, Sechtem U, Angermann C, Gola G, Prondzinsky R, Edelmann F, Spethmann S, Schellong SM, Schulze PC, Bauersachs J, Wellge B, Schoebel C, Tajsic M, Dreger H, Anker SD and Stangl K. Efficacy of telemedical interventional management in patients with heart failure (TIM-HF2): a randomised, controlled, parallel-group, unmasked trial. *The Lancet*. 2018; 392: 1047-57.
27. Kalter-Leibovici O, Freimark D, Freedman LS, Kaufman G, Ziv A, Murad H, Benderly M, Silverman BG, Friedman N, Cukierman-Yaffe T, Asher E, Grupper A, Goldman D, Amitai M, Matetzky S, Shani M, Silber H, Admon D, Arad M, Dvorkin Y, Gercenshtein V, Klempner R, Lerner L, Menachemi DM, Mutlak D, Peled-Potashnik Y, Rispler S, Rosenblatt S, Satanovsky Y, Shohat-Zabarski R, Socher E, Vered Z and Zwas DR. Disease management in the treatment of patients with chronic heart failure who have universal access to health care: A randomized controlled trial. *BMC Medicine*. 2017; 15.
28. Ong MK, Romano PS, Edgington S, Aronow HU, Auerbach AD, Black JT, De Marco T, Escarce JJ, Evangelista LS, Hanna B, Ganiats TG, Greenberg BH, Greenfield S, Kaplan SH, Kimchi A, Liu H, Lombardo D, Mangione CM, Sadeghi B, Sadeghi B, Sarrafzadeh M, Tong K and Fonarow GC. Effectiveness of Remote Patient Monitoring After Discharge of Hospitalized Patients With Heart Failure: The Better Effectiveness After Transition -- Heart Failure (BEAT-HF) Randomized Clinical Trial. *JAMA internal medicine*. 2016; 176: 310-8.

29. Chatwin M, Hawkins G, Panicchia L, Woods A, Hanak A, Lucas R, Baker E, Ramhamdany E, Mann B, Riley J, Cowie MR and Simonds AK. Randomised crossover trial of telemonitoring in chronic respiratory patients (TeleCRAFT trial). *Thorax*. 2016; 71: 305-11.
30. Udsen FW, Lilholt PH, Hejlesen O and Ehlers L. Cost-effectiveness of telehealthcare to patients with chronic obstructive pulmonary disease: Results from the Danish TeleCare North' cluster-randomised trial. *BMJ Open*. 2017; 7.
31. Sink E, Patel K, Groenendyk J, Peters R, Som A, Kim E, Xing M, Blanchard M and Ross W. Effectiveness of a novel, automated telephone intervention on time to hospitalisation in patients with COPD: A randomised controlled trial. *Journal of telemedicine and telecare*. 2018: 1357633x18800211.
32. Achelrod D, Schreyogg J and Stargardt T. Health-economic evaluation of home telemonitoring for COPD in Germany: evidence from a large population-based cohort. *The European journal of health economics : HEPAC : health economics in prevention and care*. 2017; 18: 869-82.
33. Bingler M, Erickson LA, Reid KJ, Lee B, O'Brien J, Apperson J, Goggin K and Shirali G. Interstage Outcomes in Infants With Single Ventricle Heart Disease Comparing Home Monitoring Technology to Three-Ring Binder Documentation: A Randomized Crossover Study. *World Journal for Pediatric and Congenital Hearth Surgery*. 2018; 9: 305-14.
34. Celler B, Varnfield M and Jayasena R. What Have We Learned from the CSIRO National NBN Telehealth Trial? *Studies in health technology and informatics*. 2018; 246: 1-17.
35. De Luca R, Bramanti A, De Cola MC, Trifiletti A, Tomasello P, Torrisi M, Reitano S, Leo A, Bramanti P and Calabro RS. Tele-health-care in the elderly living in nursing home: the first Sicilian multimodal approach. *Aging clinical and experimental research*. 2016; 28: 753-9.
36. Flaherty LR, Daniels K, Luther J, Haas GL and Kasckow J. Reduction of medical hospitalizations in veterans with schizophrenia using home telehealth. *Psychiatry research*. 2017; 255: 153-5.
37. Trucco F, Pedemonte M, Racca F, Falsaperla R, Romano C, Wenzel A, D'Agostino A, Pistorio A, Tacchetti P, Bella C, Bruno C and Minetti C. Tele-monitoring in paediatric and young home-ventilated neuromuscular patients: A multicentre case-control trial. *Journal of telemedicine and telecare*. 2019; 25: 414-24.
38. D'Ancona G, Safak E, Senges J, Hochadel M, Nguyen VL, Perings C, Jung W, Spitzer S, Eckardt L, Brachmann J, Seidl K, Hink HU, Ince H and Ortak J. Activation of remote monitoring for cardiac implantable electronic devices: small dog for tall weeds. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2017; 106: 833-9.
39. Parthiban N, Esterman A, Mahajan R, Twomey DJ, Pathak RK, Lau DH, Roberts-Thomson KC, Young GD, Sanders P and Ganesan AN. Remote monitoring of implantable cardioverter-defibrillators: a systematic review and meta-analysis of clinical outcomes. *Journal of the American College of Cardiology*. 2015; 65: 2591-600.
40. Schreier G, Eckmann H, Hayn D, Kreiner K, Kastner P and Lovell N. Web versus App - compliance of patients in a telehealth diabetes management programme using two different technologies. *Journal of telemedicine and telecare*. 2012; 18: 476-80.
41. Bohingamu Mudiyanselage S, Stevens J, Watts JJ, Toscano J, Kotowicz MA, Steinfort CL, Bell J, Byrnes J, Bruce S, Carter S, Hunter C, Barrand C and Hayles R. Personalised telehealth intervention for chronic disease management: A pilot randomised controlled trial. *Journal of telemedicine and telecare*. 2019; 25: 343-52.
42. Agboola S, Jethwani K, Khateeb K, Moore S and Kvedar J. Heart failure remote monitoring: evidence from the retrospective evaluation of a real-world remote monitoring program. *Journal of medical Internet research*. 2015; 17: e101.
43. Klersy C, De Silvestri A, Gabutti G, Raisaro A, Curti M, Regoli F and Auricchio A. Economic impact of remote patient monitoring: an integrated economic model derived from a meta-analysis of randomized controlled trials in heart failure. *European journal of heart failure*. 2011; 13: 450-9.

44. Boriani G, Da Costa A, Quesada A, Ricci RP, Favale S, Boscolo G, Clementy N, Amori V, Mangoni di SSL and Burri H. 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. *European journal of heart failure*. 2017; 19: 416-25.
45. Nancarrow S, Banbury A and Buckley J. Evaluation of a National Broadband Network-enabled Telehealth trial for older people with chronic disease. *Australian Health Review*. 2016; 40: 641-8.
46. Peretz D, Arnaert A and Ponzoni NN. Determining the cost of implementing and operating a remote patient monitoring programme for the elderly with chronic conditions: A systematic review of economic evaluations. *Journal of telemedicine and telecare*. 2018; 24: 13-21.

Figures

Supplementary Information

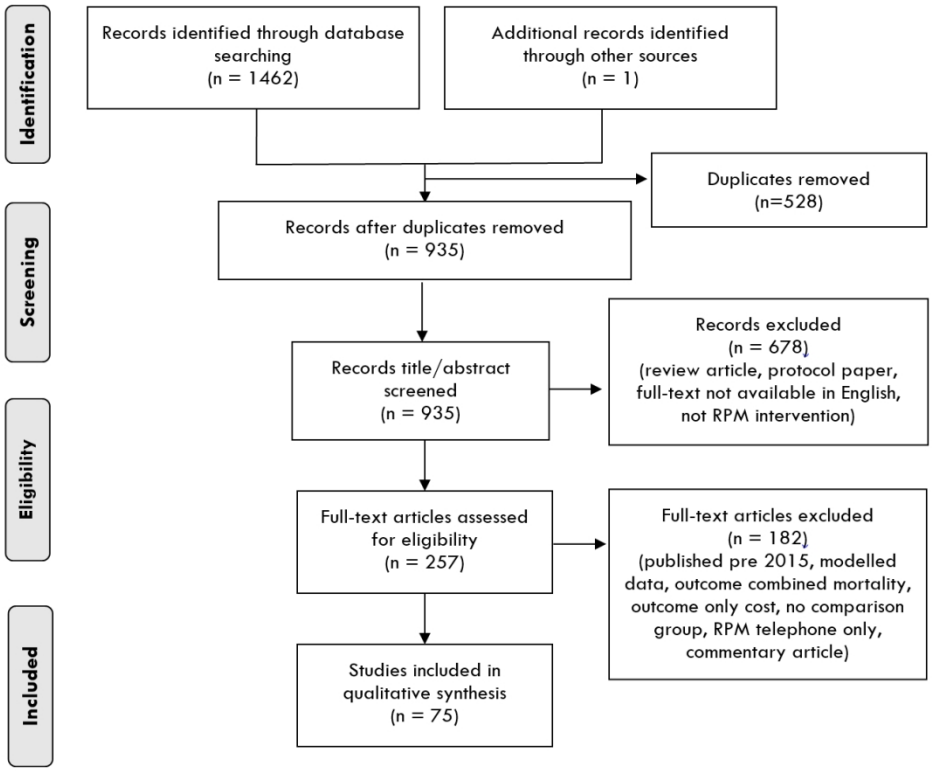

Figure 1. PRISMA flow diagram of screening process and study selection. (RPM= remote patient monitoring)

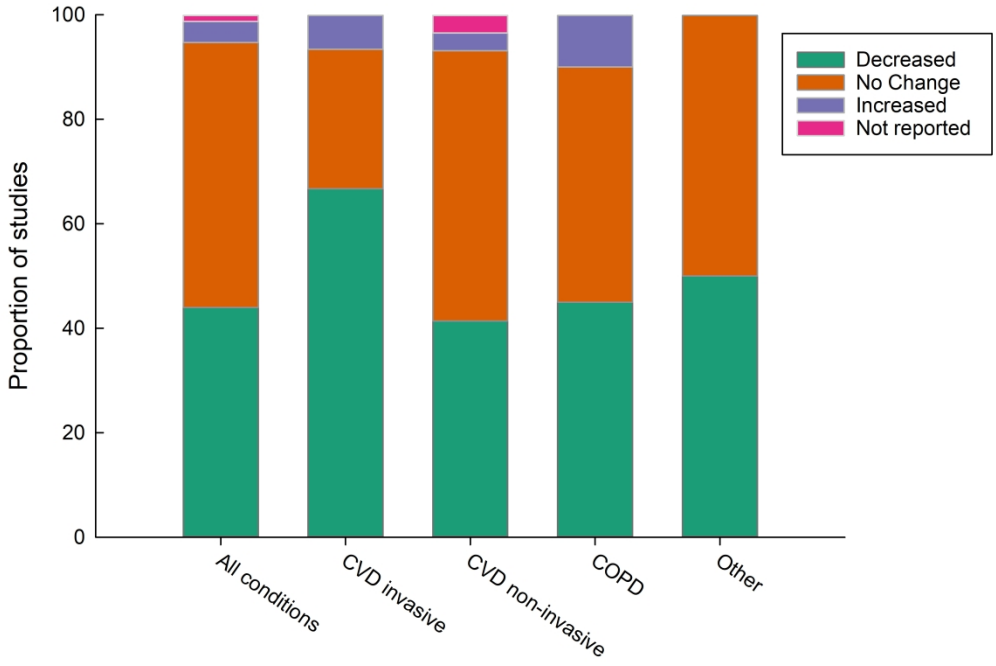

Figure 2. Effect on RPM on hospitalisation

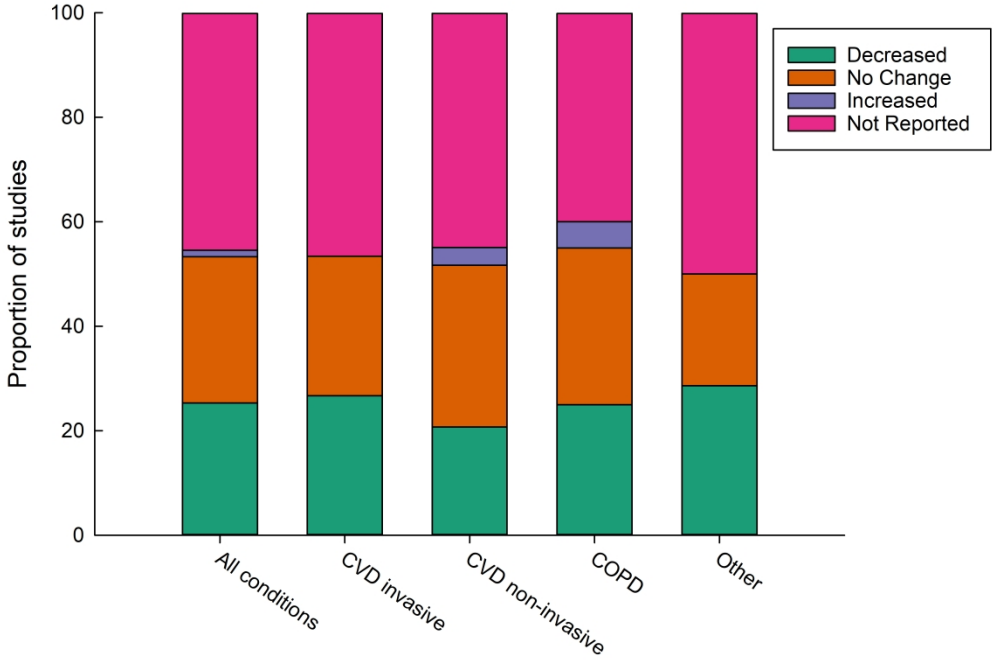

Figure 3. Effect of RPM on length of stay

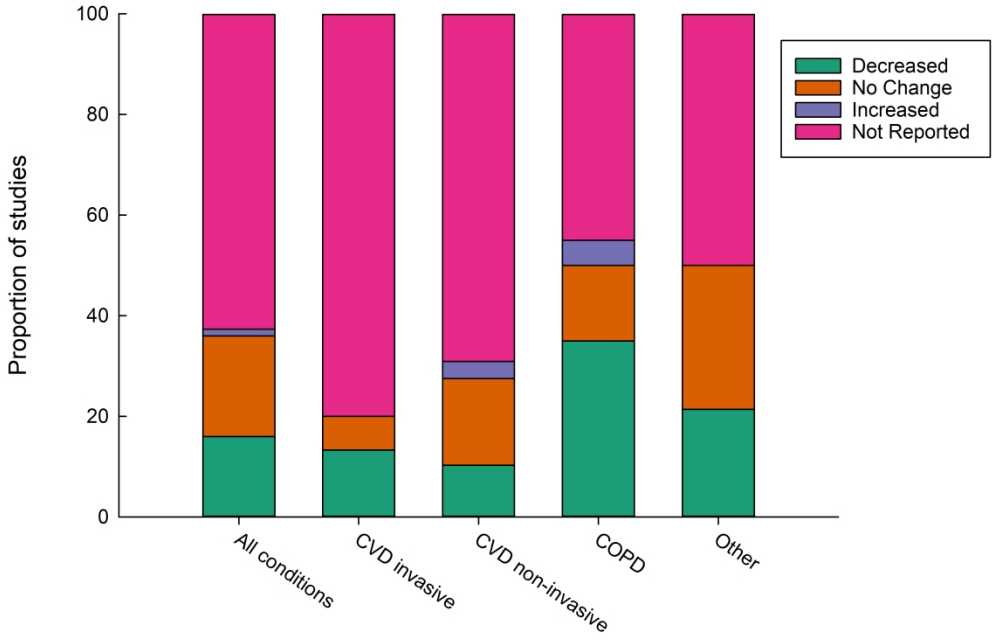

Figure 4. Effect of RPM on ED presentations

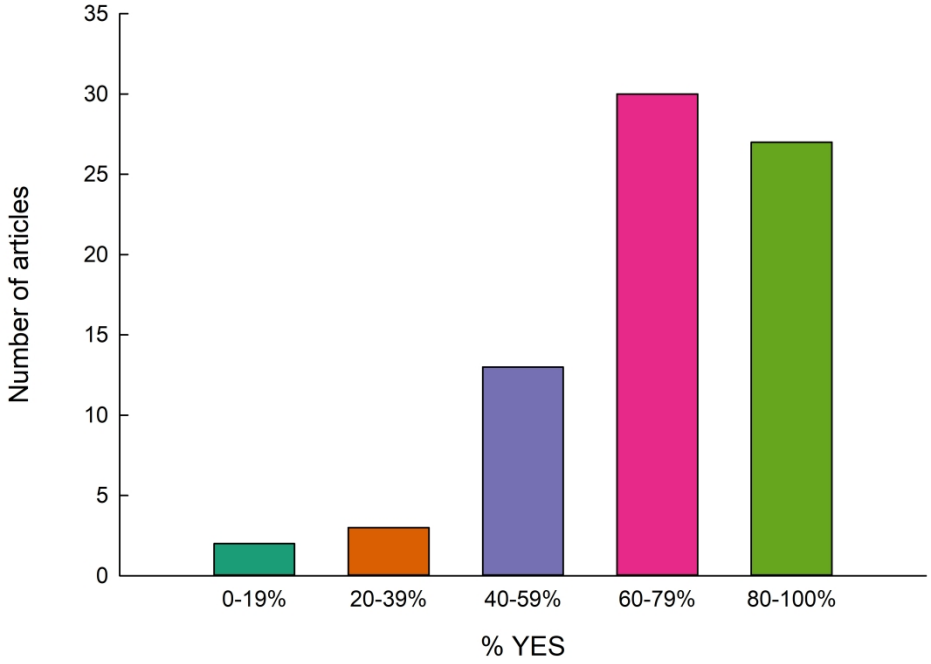

Figure 5. Number of articles by percentage of "Yes" responses to questions on the Joanna Briggs Institute critical appraisal checklists

Supplementary Table 1. Study characteristics

First Author, Year (Country)	Study type	Patient group	Trial length (approx. months)	Sample size	Average/Mean age	M/F split	RPM device	Data collection type	Data review type (Active, Passive - alert)	Supplementary support modes	OUTCOME: All cause, condition-specific, both, or not specified	Outcome findings as reported by authors in article	Summary of RPM effect on acute care use
Achelrod, 2017 (Germany)	Cohort	COPD	Baseline 24, Follow up 12	651 intervention; 7047 control	64.24 (Int); 69.47 (control before); 64.24 (control after)	43.93% female (Int); 49.17 (control before); 43.93 (control after)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	Hospitalisations due to all causes (-15.16 %, p<0.0001), due to COPD (-20.27 %, p<0.0001) and COPD-related ED presentations (-17.00 %, p<0.0001) were consistently lower in RPM patients, leading to fewer all-cause (-0.21, P<0.0001), COPD-related (-0.18, p\0.0001) and COPD-related ED presentations (-0.14, P<0.0001). On average, people in RPM group spent 3.1 (P<0.0001) and 2.07 (P<0.001) fewer days in hospital due to all causes and COPD, respectively, than control group.	Decreased
Agboola, 2015 (USA)	Cohort	Heart failure	4	174 intervention; 174 control	76.66 (10.71 SD) (Int); 76.76 (10.71 SD) (control)	58.62% male (Int & control)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Compared with controls, hospitalisation rates decreased within first 30 days of program enrollment (HR = 0.52, 95% CI 0.31-0.86, P=.01); Mean LOS similar in both groups (7 (8.92) RPM vs. 8 (8.83) control, P = 0.92).	Decreased hospitalisation, no significant difference in LOS
Akar, 2015 (USA)	Cohort	Patients with CIEDs (unspecified)	6	20852 intervention; 16890 control	67.5 (SD 12.1, 21-89) (Int); 66.5 (SD 13.0, 21-89)	70.9% male (Int); 72.6% male (control)	CIED	Automatic	Passive	Not stated	All-cause	Risk of rehospitalisation of RPM patients (n=9150, 60%) lower than those not using RPM (HR= 0.82, 95% CI 0.80–0.84, P<0.0001).	Decreased
Alshabani, 2019 (USA)	Cohort	COPD	12	39	68.6 (9.9)	M:F 20:19	Electronic inhaler monitoring device	Automatic	Passive	Not stated	All-cause and condition-specific	RPM associated with reduction in COPD-related ED presentations and hospitalisations combined per year - 2.2 (± 2.3) vs. 3.4 (± 3.2), p=0.01. All-cause this was also was reduced, although difference was NS (3.4 (2.6) vs. 4.7 (4.1), P = 0.06).	Decreased condition-specific, no significant difference all-cause
Amara, 2017 (France)	RCT	Patients with CIEDs (unspecified)	12	291 intervention; 304 control	79 (±8) (all, Int, and control)	63% male (all); 64% male (Int); 61% male (control)	CIED	Automatic	Passive	Not stated	Condition-specific	In RPM group, 39 patients (13.4%) had CV-related hospitalisations vs. 42 patients (13.8%) in control group (NS); Mean LOS was 10 ± 14 days in the RPM vs. 11 ± 13 days in the control group (NS).	No significant difference
Amir, 2017 (Israel)	Cohort	Heart failure	Varied - <12	50	73.8 ± 10.3	62% male	Dedicated RPM unit + peripheral devices	Automatic	Passive	Not stated	Condition-specific	The HR for hospital readmission rates between the pre-RPM period and the RPM period was 0.07 (95% CI 0.01–0.54, P = 0.01).	Decreased
Bingler, 2018 (USA)	RCT	Heart disease - infants	Few months	31	1.44 (0.80 to 2.13) (1 month group); 0.70 (0.47 to 1.43) (2 month group)	56.2% female (1 month grp); 26.7% female (2 month group)	Tablet	Manual	Both	Not stated	Not specified	Higher risk of having a high resource ultilisation admission in control than RPM group (RR = 2.19, 95% CI 1.16-4.12, P = 0.016); Total LOS per 100 interstage days was significantly lower with RPM vs usual care. Difference in admissions NS - RPM 26 (0.9) vs. control 19 (1.0) - P = 0.75; Total ED presentations (ED presentations per 100 interstage days) RPM 20 (0.7) vs. control 13 (0.7) (P = 0.96).	Decreased
Bohingamu Mudiyansela ge, 2019 (Australia)	RCT	COPD and/or Diabetes	12	86 intervention; 85 control	70.7 ± 11.56 (Int); 70.13 ± 13.26 (control)	60% male (Int); 47% male (control)	Tablet + peripheral devices	Manual	Both (out of hours alerts)	VC	Not specified	Lower mean acute hospital LOS over 12 months in RPM (4.6 vs. 8.7 days; 95% CI: -8.6 to -0.4); Difference in hospitalisations NS (proportion of participants who had at least one hospitalisation 53% vs. control 55%, P = 0.813).	Decreased LOS, no significant difference in hospitalisations
Böhm, 2016 (Germany)	RCT	Heart failure	~24	175 intervention; 167 control	66.1 ± 10.1 (Int); 66.4 ± 10.7 (control)	77.2% male (Int); 82.3% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific (condition-specific result reported)	The number of HF hospitalisations per patient per year 0.24 for the RPM group and 0.30 for the control (P = 0.20).	No significant difference
Boriani, 2017 (Various - Europe and Israel)	RCT	Heart failure	~24	437 intervention; 428 control	66 ± 11 (Int); 67 ± 10 (control)	78.8% male (Int); 73.1% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	ED presentations (not followed by hospitalisation) significantly lower in RPM (IRR = 0.72, 95% CI 0.53–0.98, P = 0.04); Burden of CV-related healthcare resource utilization was 38% lower in RPM vs. control (IRR = 0.62, 95% CI 0.58–0.66, P<0.001); All-cause hospitalisation rates, estimated as the 2-year rate per 100 patients, were 96 (95% CI 86–106) and 90 (95% CI 80–100, P = 0.83), respectively. CV-related hospitalisations were 197 (111 due to HF) and 200 (103 due to HF) in RPM and control, respectively.	Decreased ED but increased unscheduled visits
Buchta, 2017 (Poland)	Cohort	Patients with CIEDs (unspecified)	24	287 intervention; 287 control	61.94 (53.25 – 70.75) (Int); 62.80 (56.04 – 69.51) (control)	84% male (both)	CIED	Automatic	Passive	Not stated	All-cause	No reduction in the number of defined medical contacts. Hospitalisations (P=NS) in control vs. RPM, respectively, in year 1, 2, 3 hospitalisations Year 1= 1.4 vs. 1.16; Year 2 = 0.74 vs. 0.42; Year 3= 0.55 vs. 0.36.	No significant difference
Bulava, 2016 (Czech Republic)	RCT	Patients with CIEDs (unspecified)	26	97 intervention; 101 control	66 ± 11 (Int); 68 ± 12 (control)	83.5% male (Int); 78.2% male (control)	CIED + dedicated RPM unit	Automatic	Passive	Telephone	Not specified	LOS shorter in RPM group (10.3 ± 8.1 days, median: 8.0 days) vs. control group (17.5 ± 19.9 days, with median of 10.5 days, P = 0.027); 213 hospitalisations in total: 124 (58.2%) in control group and 89 (41.8%) in RPM group (P = 0.127).	Decreased
Capucci, 2017 (Italy)	Cohort	Patients with CIEDs (HF)	12	499 intervention; 488 control	66 (12) (Int); 65 (13) (control)	77% male (both)	CIED	Automatic	Passive	Not stated	Not specified	Rate of hospitalisations in first 12 months of follow-up was 0.16 and 0.27/year in RPM and control group, respectively (RR = 0.59; P = 0.004).	Decreased
Celler, 2018 (Australia)	Cohort	Chronic conditions (unspecified)	9	114 intervention; 173 control	71.1 (9.3) (Int); 71.9 (9.4) (control)	64% male (Int); 56% male (control)	Dedicated RPM unit	Manual	NS	Not stated (But said reminded to record vitals?)	Not specified	RPM patients significant (P = 0.006) reduction in rate of hospitalisations vs. controls (P = 0.869); After one year of RPM average expected LOS reduced by almost 68% from predicted value of 24.6 to 7.9 days.	Decreased

Chatwin, 2016 (UK)	RCT	Chronic lung disease (COPD and chronic resp failure)	6	38 intervention; 34 control	61.8 (11.9)	48% males	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	Respiratory hospitalisations for acute exacerbations at 6 months increased in RPM group — frequency 0.32 control vs. 0.63 RPM (mean difference 0.32, P = 0.026). Although time to first admission did not change, actual hospitalisations doubled from 18 to 36.	Increased
Clarke, 2018 (UK)	Cohort	COPD	3 monitor, 12 pre data	227	70.9 ± 8.9	50% males	Dedicated RPM unit + peripheral devices	Manual	Active	RM unit message	All-cause and condition-specific	Average LOS decreased in one group from 11.5 in period 12 months before to 6.5 days during RPM; In other group average LOS decreased 7.5 to 5.2 days; For all other causes there was a reduction in LOS during RPM period vs. period 12 months before (9%) but an increase (10%) vs. period immediately before RPM; COPD hospitalisations increased from 64 to 71; Other hospitalisations decreased 43 to 39.	Decreased LOS, variability in hospitalisations, and changed if compared to immediate pre or 12 months pre.
Comin-Colet, 2016 (Spain)	RCT	Heart failure	6	81 intervention; 97 control	74 ± 11 (Int); 75 ± 11 (control)	43% female (Int); 39% female (control)	Tablet	Manual	Active	Telephone, VC	All-cause and condition-specific	HF readmission (HR = 0.39, CI 0.19–0.77, P = 0.007) and CV readmission (HR = 0.43, CI 0.23–0.80, P = 0.008) were reduced in RPM group; mean LOS significantly reduced in RPM group for all cause, HF and CV readmissions. In patients hospitalised, mean LOS tended to be shorter in RPM group. In adjusted models, results were similar.	Decreased
D'Ancona, 2017 (Germany)	Cohort	Patients with CIEDs (unspecified)	12	720 RM capable devices (91 activated); 503 control	68 (58-75) (Int); 67 (57-75) (control)	20% female (Int); 21.5% female (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM patients had higher re-hospitalisation rate (45.2% vs. 34.8%, P = 0.059).	Increased
Davis, 2015 (USA)	Cohort	HF, COPD	3	117 intervention; 233 control	COPD: 61 (11) (Int); 63 (15.8) (control) HF: 62 (16.6) (Int); 65 (14.6) (control)	COPD: 62.1% female (Int); 60.3% female (control) HF: 45.8% female (Int); 56% female (control)	Dedicated RPM unit	Manual	Passive	Telephone, Dedicated RM unit message	All-cause	30-day re-admissions were reduced 50% for both chronic disease cohorts vs. control (COPD, 10.3% vs. 21.8%, HF, 8.5% vs. 17%); 37% reduction in ED presentations in the 30-day postdischarge period for COPD cohort compared with control patients (6.9% vs. 10.9%), but 75% increase in ED presentations for the HF cohort (11.9% vs. 6.8%) in the 30 days after the index discharge; Admissions 150 to 49 in COPD but 50 to 52 in HF.	Decreased for COPD, increased ED and hospitalisations for HF
De Luca, 2016 (Italy)	RCT	Nursing home patients; Mental health	Not specified	32 intervention; 27 control	77 (71-80) (Int); 85 (79-89) (control)	34.4% male (Int); 29.6% male (control)	Dedicated RPM unit + peripheral devices	Manual? (had to connect to machine, but once connected automatically transmitted)	Active	VC	Not specified	Admission to health care service was higher (x^2 = 3.96, P<0.05) in control group (8/27) vs. RPM group (3/32).	Decreased
De Simone, 2015 (Italy)	Non-randomised controlled trial/Quasi-experimental	Patients with CIEDs (unspecified)	24	499 intervention; 488 control	66 ± 12 (Int); 66 ± 13 (control)	76% male (Int); 78% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	RPM reduced risk of all-cause hospitalisations (87 vs. 129; 0.15 vs. 0.28 events/ year; IRR = 0.54, 95% CI 0.41–0.71, P < 0.001) and CV hospitalisations (60 vs. 89; 0.11 vs. 0.20 events/year; IRR = 0.54, 95% CI 0.38–0.75, P < 0.001) vs. control group; LOS was 517 days (0.91 days/year) in RPM group and 974 days (2.15 days/year) in control group.	Decreased
De Simone, 2019 (Italy)	Cohort	Patients with CIEDs (AF)	12	26 intervention; 45 control	82 [79–87] (Int); 85 [78–89] (control)	34.6% female (Int); 53.3% female (control)	CIED	Automatic	Passive	Not stated	All-cause	All-cause hospitalisations were 33, with lower event rate in RPM group vs. control (5.8; 95% CI 3.3–9.4 vs. 9.7; 95% CI 6.5–13.9 per 100 patient-months; P = 0.027); RR with RPM was significant for all-cause hospitalisation (RR= 0.44, 95% CI 0.21–0.93).	Decreased
Esteban, 2016 (Spain)	Cohort	COPD	24	120 intervention; 78 control	71.34 (Int); 70.1 (control) ALL: 70.83	86.6% male (Int); 87.2% male (control) ALL: 86.8% male	Smartphone	Manual	Active	Telephone	Condition-specific	After 2 years, both cohorts showed reduction in rate of hospitalisations (P<0.001) but reduction was significantly higher in RPM group (1.14 vs. 2.33, P<0.001); Significant differences in rate of ED presentations (pre-post = 0.4 (0.1–0.6) P = 0.006), cumulative LOS, and rate of 30-day readmission during study period; In multivariate analysis, being in the RPM group was independently associated with lower rates of hospitalisations (IRR = 0.38, 95% CI 0.27–0.54, P<0.0001), ED presentation (IRR = 0.56, 95% CI 0.35–0.92, P<0.02), and 30-day readmission (IRR = 0.46, 95% CI 0.29–0.74, P<0.001), as well as cumulative LOS (IRR = 0.58, 95% CI 0.46–0.73, P<0.0001).	Decreased

Flaherty, 2017 (USA)	RCT	Schizophrenia	3	20 intervention; 25 control	49.9 ± 12.7 (Int); 51.2 ± 11.1 (control)	90% male (Int); 96% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Not specified	RPM group significantly less likely vs. control group to have at least one hospitalisation (5.0% vs. 32.0%, P<0.05). Also, RPM group had significantly lower average number of hospitalisations (0.10 ± 0.45 vs. 0.60 ± 1.19, Mann Whitney U=4.67, df=1, P<0.05). RPM group also had significantly lower mean LOS (0.70 ± 3.13 vs. 2.56 ± 6.11, Mann Whitney U,=4.59, df=1, P<0.05). No significant differences were found between groups in terms of numbers of psychiatric hospitalisations (0.65 ± 1.04 vs. 0.52 ± 0.77). Additionally, RPM and control groups did not differ on ED presentations (0.60 ± 1.23 vs. 0.92 ± 1.19).	Decreased hospitalisations, no significant difference on ED
Geller, 2019 (Germany)	RCT	Patients with CIEDs (HF)	12	333 intervention; 331 control	ICD 65 [58–70]; CRT-D 68 [62–74]; (control not reported)	ICD 85.0% male; CRT-D 77.7% male; (control group not reported)	CIED	Automatic	Passive	Not stated	All-cause	Hospitalisations for worsening HF in RPM vs. control group was 14 vs. 13 (ICD) and 30 vs. 34 (CRT-D). Number of affected patients was 10 vs. 8 (ICD: 7.0% vs. 6.1%, P = 0.81) and 17 vs. 26 (CRT-D: 8.9% vs. 13.0%; P = 0.26), the median length of hospital stay was 9.0 vs. 7.0 days (ICD: P = 0.38) and 7.0 vs. 7.5 days (CRT-D: P = 0.43), respectively.	No significant difference
Gingele, 2019 (Netherlands)	RCT	Heart failure	12	197 intervention; 185 control	71.0 ± 11.9 (Int); 71.9 ± 10.5 (control)	58% male (Int); 60% male (control)	Dedicated RPM unit	Manual	Active	"contacted with advice" "twice had personal contact with specialist"	Condition-specific	RPM group had significantly fewer HF-related hospitalisations vs. control group (IRR = 0.54, 95% CI 0.31–0.88). However, HF-related LOS was not significantly shorter in RPM group (IRR = 0.60, 95% CI 0.33–1.07).	Decreased hospitalisations, no significant diference in LOS
Hale, 2016 (USA)	RCT	Heart failure	3	11 intervention; 14 control	68.4 (11.8) (intervention); 74.4 (10.4) (control)	64% male (both)	MedSentry electronic medication device	Automatic	Active? (monitoring centre with advisors)	Telephone	All-cause and condition-specific	Approximately 9% (1/11) of RPM participants were hospitalised one or more times vs. 50% (7/14) control participants (P = 0.04), a relative risk reduction in hospitalisation of approximately 82%. RPM group had significantly fewer all-cause hospitalisation days vs. controls (4 vs 34, P = 0.03) and there was a reduction in the LOS for HF-related and non-HF-related hospitalisations (NS, P = 0.24). ED presentations all cause and HF-related were reduced (NS, 6 to 3 and 3 to 1, respectively).	Decreased
Hansen, 2018 (Germany)	RCT	Patients with CIEDs (HF)	13	102 intervention; 108 control	62.5 ± 12.2 (Telemetry); 64.7 ± 9.1 (remote + phone); 65.4 ± 11.1 (visit)	16.7% female (telemetry); 13.2% female (remote + phone); 16.4% female (visit)	CIED + dedicated RPM unit	Automatic	Passive	Website	Condition-specific	HF-hospitalisation occurred at similar rates in the RPM and control groups (9.8% vs. 12.0%, P = 0.605).	No significant difference
Heidbuchel, 2015 (Various - Europe)	RCT	Patients with CIEDs (unspecified)	24	159 intervention; 144 control	62.4 ± 13.1 (ALL); 62.0 ± 13.9 (Int); 62.9 ± 12.3 (control)	80.5% male (ALL); 78% male (Int); 83.3% male	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	Fewer CV hospitalisations and shorter LOS in RPM patients, but NS. CV hospitalisations control vs. RPM = 0.85 (1.43) vs. 0.67 (1.18), P= 0.233; LOS (days) 8.26 (18.6) vs. 6.31 (15.5), P= 0.266.	No significant difference
Ho, 2016 (Taiwan)	RCT	COPD	6	53 intervention; 53 control	81.4 ± 7.8 (Int); 79.0 ± 9.6 (control)	81% male (Int); 72% male (control)	Website	Manual	Active	Not stated	All-cause and condition-specific	RPM associated with a significant reduction in number of all-cause re-admissions from 0.68 to 0.23 per patient (P = 0.002). RPM patients had fewer ED presentations for all causes vs. control group (0.36 vs. 0.91 per patient, P = 0.006).	Decreased
Ishani, 2016 (USA)	RCT	CKD	12	451 intervention; 150 control	75.3 ± 8.1 (Int); 74.3 ± 8.1 (control)	98.7% male (Int); 98.0% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	VC	All-cause	RPM did not reduce the risk for hospitalisation or ED presentations vs. usual care; Hospitalisations HR = 1.15; 95% CI 0.80-1.63, ED presentations HR = 0.92; 95% CI, 0.68-1.24.	No significant difference
Kalter-Leibovici, 2017 (Israel)	RCT	Heart failure	30	682 intervention; 678 control	70.8 (11.6) (Int); 70.7 (11.0) (control)	69.3% male (Int); 75.7% male (control)	Dedicated RPM unit	Manual	Passive	Telephone, VC	All-cause	No significant differences in LOS (adjusted RR = 0.886; 95% CI 0.749-1.048), and hospitalisations for all causes (adjusted RR = 0.935; 95% CI 0.840-1.040).	No significant difference
Kao, 2016 (USA)	Cohort	Heart failure	36	623 intervention; 623 control	78.76 ± 9.08 (Int); 77.39 ± 8.59 (control)	56.7% male (Int); 52.3% male (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	A reduction of 22.7% in quarterly hospitalisations noted in RPM vs. matched controls (D = -0.05 hospitalisations/quarter; 95% CI -0.09 to -0.01; P = 0.012). No significant differences between RPM and matched control cohorts in all-cause LOS per quarter or all-cause ED presentations.	No significant difference in LOS or ED, decreased hospitalisations

Kenealy, 2015 (New Zealand)	RCT - except site C	Chronic conditions (unspecified)	6	98 intervention; 73 control	SITE A: 72 (62–83) (Int); 72 (60–77) (control) SITE B: 67 (64–74) (Int); 67.5 (63– 72.5) (control) SITE C: 57 (53-60) (Int); no control group	SITE A: 39% female (Int); 29% female (control) SITE B: 38% female (both) SITE C: 60% female (no control group)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause	RPM group showed no significant change in hospitalisations vs. usual care (coefficient 0.32, P = 0.15), ED presentations (coefficient -0.08, P = 0.91), or LOS (coefficient 0.51, P = 0.09).	No significant difference
Kessler, 2018 (Various - Europe (France, Germany, Italy, Spain)	RCT	COPD	12	172 intervention; 173 control	67.3 ± 8.9 (Int); 66.6 ± 9.6 (control); ALL 66.9 ± 9.3	69.4% male (Int); 69.8% male (control)	Telephone	Manual	Active	Telephone	All-cause and condition-specific	No significant difference in all-cause LOS (non-parametric analysis (p=0.161) or ANOVA comparison of the mean values adjusted for country differences (−5.3 days, 95% CI −13.7 to 3.1; P = 0.212). Difference was 7.4 ± 35.4 in RPM group and 22.6 ± 41.8 in control group, with medians (IQR) of 0 (0–203) days and 5 (0 −259) days, respectively. The total numbers of unplanned hospitalisations were similar for both groups (RPM group, n=157; control group, n=160). LOS due to acute exacerbation of COPD not significantly different.	No significant difference
Koehler, 2018 (Germany)	RCT	Heart failure	12	765 intervention; 773 control	70 (11) (Int); 70 (10) (control)	70% male (Int); 69% male (control)	Tablet + peripheral devices	Manual	Active	Telephone	Condition-specific	RPM group had shorter LOS vs. control group for unplanned hospitalisations due to worsening HF (mean 3.8 days per year, 95% CI 3.5–4.1 vs. 5.6 days per year, 5·2–6·0, respectively). The percentage of days lost for this outcome for RPM and control groups was 1.04% (95% CI 0.96–1.11) and 1.53% (1.43–1.64), respectively (ratio 0.80, 95% CI 0.67–0.95; P = 0.0070).	Decreased
Koulaouzidis, 2019 (UK)	Cohort	Heart failure	12	124 intervention; 345 control	68.1 (12.7) (Int); 67.5 (10.6) (control)	78.2 male (Int); 68.1% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause hospitalisation and condition-specific readmission	There was no difference between the two groups in all-cause hospitalisation, either in number of subjects hospitalised (P = 0.7) or in number of admissions per patient P = 0.6), No difference in number of HF-related readmissions per person between the two groups (P = 0.5), but LOS per person was higher in control group (P = 0.03).	Decreased LOS, no significant difference in hospitalisation
Kraai, 2016 (Netherlands)	RCT	Heart failure	9	94 intervention; 83 control	69 ± 12 (Int); 69 ± 11 (control);	70% male (Int); 75% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	HF-readmission 28% vs. 27% P = 0.87; All-cause readmission was 49% vs. 51% (P = 0.78).	No significant difference
Kurek, 2017 (Poland)	Cohort	Heart failure	12	287 intervention; 287 control	63 (56–69) (Int); 62 (53–70) (control)	84% male (both)	CIED + dedicated RPM unit	Automatic	Passive	Not stated	Condition-specific	Number of HF-related hospitalisations in 1-year observation was comparable (1.71 vs. 1.65 visits/per patient, P = 0.27).	No significant difference
Ladapo, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	24	2849 intervention (ICD, CRT-D and PPM); 2849 matched control	*All after matching ICD: 64 (12) (Int); 65 (12) (control) CRT-D: 69(10) (both) PPM: 74 (11) (both)	*All after matching ICD: 79% male (both) CRT-D: 73% male (both) PPM: 55% male (both)	CIED	Automatic	Passive	Not stated	Not specified	RPM patients less likely to have ED presentations (P = 0.050) and had fewer hospital stays (P = 0.057). RPM patients did not significantly differ from control in ED presentations or hospital care. RPM patients over a 24-month period similar or less frequent utilization of emergency and hospital care, compared with those followed in the office (reductions in utilization most pronounced among ICDs).	Decreased
Lanssens, 2017 (Belgium)	Cohort	Gestational hypertensive disorders	12	48 intervention; 98 control	31.69 (4.25) (Int); 31.94 (4.77) (control)	100% females (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated (Telephone? "Contacting patients at home")	Not specified	Prenatal hospitalisations and hospitalisations until delivery were lower in RPM vs. control when a univariate analysis was performed - 56.25% (27/48) vs.74.49% (73/98) and 27.08% (13/48) vs. 62.24% (61/97). This was not significant in multivariate analysis.	No significant difference in multivariate analysis, decreased in univariate analysis.
Lanssens, 2018 (Belgium)	Cohort	Gestational hypertensive disorders	12	90 intervention; 320 control	30.97 (±5.61) (Int); 30.53 (±5.17) (control)	100% females (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated (Telephone? "Contacting patients at home")	Not specified	In both uni- and multivariate analyses, RPM group had, vs. control group, less prenatal admission (51.62% vs. 71.63%), and less prenatal admissions until the moment of the delivery (31.40% vs. 57.67%).	Decreased

Lew, 2018 (USA)	Cohort	Peritoneal dialysis patients	Not specified	269	56 (43.6–64.3)	56.9% males	Peripheral devices	Manual	Active	VC	Not specified	Use of RPM collected weight associated with fewer hospitalisations (adjusted OR= 0.54, 95% CI 0.33–0.89) and shorter LOS (adjusted OR = 0.46, 95% CI 0.26–0.81). Use of RPM collected BP associated with longer LOS (adjusted OR = 1.95, 95% CI 1.10–3.46) and increased odds of hospitalisation (adjusted OR 1.65, 95% CI 1.02–2.65).	Decreased (when monitoring weight), increased (when monitoring BP).
Lu¨thje, 2015 (Germany)	RCT	Patients with CIEDs (unspecified)	15	73 intervention; 82 control	66.0 (± 12.0) (Int); 65.9 (± 12.1) (control)	80.5% males (Int); 74.2% males (control)	CIED	Automatic	Passive	Telephone	Condition-specific	The mean number of ED presentations was not significantly different between the two groups (RPM group 0.10 + 0.25 vs. control group 0.10 + 0.23; P = 0.7295). 20 RPM patients and 22 control patients were hospitalised for worsened HF (no significance test stated).	No significant difference
Lyth, 2019 (Sweden)	Cohort	HF, COPD	12	94	HF: 84 (65–100) COPD: 74 (65–86)	HF: 50% females COPD: 61.1% females	Digital pen and Health Diary System	Manual	Active	SMS	Condition-specific	Hospitalisations was 0.94 for HF and 1.16 for COPD. This was significantly lower than expected, with 67% in the HF group (P<0.001) and 61% in the COPD group (P = 0.003). Mean values for inpatient care and emergency care in HF and COPD significantly lower in observed vs. expected (P<0.001).	Decreased
Martin-Lesende, 2017 (Spain)	Cohort	HF, COPD or other chronic lung disease	12	28	78.9 (7.5)	45.3% males	Smartphone	Manual	Passive? (Red/yellow alerts on web platform)	SMS	All-cause and condition-specific	Significant reduction in hospitalisations, from 2.6 admissions/patient in the previous year (SD: 1.6) to 1.1 (SD: 1.5) during the one year RPM follow-up (P<0.001), and ED presentations, from 4.2 (SD: 2.6) to 2.1 (SD: 2.6) (P<0.001) was observed. The LOS was reduced non-significantly from 11.4 to 7.9 days.	Decreased hospitalisations and ED, no significant difference in LOS
McDowell, 2015 (UK)	RCT	COPD	6	48 intervention; 52 control	69.8 (7.1) (Int); 70.2 (7.4) (control)	58.2% females (Int); 54.5% females (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated - "Contacted patient" (Telephone?)	Not specified	At 6 months there was a higher number of ED presentations, hospitalisations and longer LOS in control group vs. RPM group, but differences were NS (P = 0.40, P = 0.42, P = 0.59 respectively).	No significant difference
McElroy, 2016 (USA)	Cohort	Patients post surgery (cardiac)	1	27 intervention; 416 control	62.9 (9.8) (intervention); 65.9 (14.1) (control)	85.2% male (Int); 65.9% male (control)	Tablet + peripheral devices	Manual	Active	Telephone, VC	Not specified	Readmission rate for the RPM and control groups were similar (7.4% vs. 9.9%, P = 0.65). LOS 9.1 ± 9.0 vs. RPM 8.7 ± 3.6 P = 0.65.	No significant difference
Mirón Rubio, 2018 (Spain)	Cohort	COPD	6	26	78 (7.9)	93% males	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone, In-person	Not specified	The number of ED presentations decreased by 38%, from 53 visits during control period (in 26 (92.9%) patients; mean 1.89 visits/patient; range 0–6) to 33 visits during RPM period (in 15 (53.6%) patients; mean 1.18 visits/patient; range 0–6, p = 0.03). Fewer hospitalisations or ED presentations during RPM period: only 15 patients (53.6%) vs. 26 (92.8%) patients during control period (RR = 0.58; CI 95% 0.40 – 0.83, P =0.002).	Decreased
Nancarrow, 2016 (Australia)	Cohort	Geriatric	12	200	74.8 ± (8.2)	41.5% male	Tablet + peripheral devices	Manual	Active	VC	Not specified	Self-reported health service use showed decline in ED presentations (X^2= 14.950, n = 122; 6 df, P = 0.021); hospitalisation (non-local) (x^2 61.44, n = 118, 12 df, P< 0.001). However, there was no significant difference in hospitalisation in the local hospital (c^2 21.190, n = 122; 16 df, P = 0.171).	Decreased ED, no significant difference local hospitalisations
Nouryan, 2019 (USA)	RCT	Heart failure	6	42 intervention; 47 control	81.4 (Int); 84.9 (control)	32% male	Dedicated RPM unit + peripheral devices	Manual	Active	VC, Feedback reports to patient as well	All-cause and condition-specific	38% of RPM patients had ≥1 ED presentation vs. 60% of control (P = 0.04), while 48% of RPM had ≥1 hospitalisation vs. 55% of control (P = 0.47). LOS (days) was 4.0 for RPM vs. 7.4 for control (P = 0.39).	Decreased ED, hospitalisation and LOS not significantly different
Olivari, 2018 (Italy)	RCT	Heart failure	12	229 intervention; 110 control	79.6 ± 6.8 (Int); 80.9 ± 7.3 (control)	61.1% male (Int); 65.4% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Not stated	All-cause	in the RPM and control group respectively, mean LOS of 13.1 ± 16.3 and 16.5 ± 32.0 (P = 0.21) days. Hospitalisations for HF occurred in 161 and 93, with a mean LOS of 13.5 ± 14.2 and 19.0 ± 39.3 (P = 0.20) days, in the RPM and control group, respectively.	No significant difference
Ong, 2016 (USA)	RCT	Heart failure	6	715 intervention; 722 control	73 (62-84) (Int); 74 (63-82) (control)	46.6% (42.9-50.2) female (Int); 47.1% female (42.8-51.4) (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	All-cause	The RPM and control groups did not differ significantly in readmissions for any cause 180 days after discharge, which occurred in 50.8% (363 of 715) and 49.2% (355 of 722) of patients, respectively (adjusted HR = 1.03; 95% CI 0.88-1.20; P = 0.74).	No significant difference
Orozco-Beltran, 2017 (Spain)	Quasi-experimental	Chronic conditions (unspecified)	12	521	70.4 (10.3)	38.9% female	Tablet	Manual	Passive	Telephone, VC	All-cause and condition-specific	Decrease in ED presentations (98, 18.8% vs. 67, 12.8%; P<.001). Fewer hospitalisations due to an emergency (105, 20.2% vs. 71, 13.6%; P<.001) or disease exacerbation (55, 10.5% vs. 42, 8.1%; P<.001).	Decreased
Pedone, 2015 (Italy)	RCT	Heart failure	6	50 intervention; 46 control	79.9 ± 6.8 (Int); 79.7 ± 7.8 (control)	46.8% males (Int); 30.2% males (control)	Smartphone + peripheral devices	Manual	Active? (doctor reviewed each day but still had alerts)	Telephone	All-cause	Hospitalisations during the 6 months of follow-up: 20 in control group (incidence rate 129/100 person-years, 95% CI = 84–200) and 8 (incidence rate 39/100 person-years, 95% CI = 20–77) in RPM group (IRR = 0.30, 95% CI 0.12–0.67).	Decreased

Pekmezaris, 2019 (USA)	RCT	Heart failure	3	46 intervention; 58 control	58.4 (15.2, 19–93) (Int); 61.1 (15.0, 26–90) (control)	43% female (Int); 40% female (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone, VC	All-cause and condition-specific	Groups did not differ regarding binary ED presentations (RR = 1.37, CI 0.83–2.27), hospitalization (RR = 0.92, CI 0.57–1.48), or length of stay in days (RPM = 0.54 vs. control =0.91). Number of all-cause hospitalisations was significantly lower for control (RPM= 0.78 vs. control = 0.55; P = 0.03).	No significant difference in binary ED, hospitalisation, or LOS, increased for all-cause hospitalisation
Piccini, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	19	34,259 intervention; 58,307 control	69.7 ± 12.7 (Int); 72.6 ± 13.1 (control)	66.1% male (Int); 60.9% male (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM had lower adjusted risk of all-cause hospitalisation (adjusted HR = 0.82; 95% CI 0.80–0.84; P = 0.001) and shorter mean LOS (5.3 days vs. 8.1 days, P < 0.001).	Decreased
Ricci, 2017 (Italy)	Quasi-experimental	Patients with CIEDs (unspecified)	12	102 intervention; 107 control	69.69 ± 10.17 (Int); 68.89 ± 11.46 (control)	84.31% male (Int); 85.98% (control)	CIED + transmitter	Automatic	Passive	Dedicated RM unit message	Condition-specific	More CV-related hospitalisations in control vs. RPM patients (SC: 22 (24.72%) vs. RPM: 7 (8.14%); P = 0.0032); more ED presentations (control: 5 (5.62%) vs. RPM: 0 (0.00%); P = .059); Regarding CV hospitalisations, there was no statistically significant difference in LOS between patients with RPM and control patients (6.6 ± 4.7 days [44 hospitalizations] vs. 6.4 ± 4.8 days [14 hospitalizations], P = 0.8990).	Decreased ED and hospitalisations, no significant difference in LOS
Riley, 2015 (USA)	Cohort	Heart failure	6	45 intervention; 45 control	*Of those matched 65.9 (14.7)	*Of those matched 48.9% females	Smartphone + peripheral devices	Manual	Active	Not stated	Not specified	Matched cohort saw similar decrease pre/post as RPM saw pre/post. For comparing directly enrolled vs. matched at 30 days post - 0.47 (1.10) vs. 0.56 (0.87); 60 days 1.24 (3.24) vs. 0.87 (1.44); 182 days 1.87 (4.54) vs. 1.22 (1.71). For enrolled vs. matched, at 30 days, time F (1,88) = 43.87, p < 0.0001, time · group = 0.63, p = 0.429; at 90 days, time F (1,88) = 50.87, p < 0.0001, time · group = 0.12, p = 0.727; and at 182 days, time F (1,88) = 45.36, p < 0.0001, time · group = 1.00, p = 0.320.	No significant difference
Ringbæk, 2015 (Denmark)	RCT	COPD	6	141 intervention; 140 control	69.8 (9.0) (Int); 69.4 (10.1) (control)	61% females (Int); 45% females (control)	Tablet + peripheral devices	Manual	Active	VC	Condition-specific	No significant difference found in hospital admissions for COPD between the groups (P = 0.74).	No significant difference
Rosner, 2018 (USA)	Cohort	Patients post surgery (orthopaedic)	3	186 intervention; 372 control;	57.00 (7.32)	50% females	Website	Manual	Active	E-mail	Not specified	90 day hospitalisation rates in baseline and RPM groups were 3.0% (11 of 372) and 1.6% (3 of 186), respectively (RR = 0.545; CI 0.154 - 1.931, P = 0.40).	No significant difference
Sardu, 2016 (USA)	RCT	Heart failure	12	89 intervention; 94 control	71.8 ± 8.5 (Int); 72.6 ± 5.7 (control)	71.9 males (Int); 79.8% males (control)	CIED	Automatic	Active	Telephone, In-person	Condition-specific	There was a significant difference in hospitalisations (15.7 vs. 28.7, P = 0.02) comparing RPM patients to control group. At multivariate analysis, RPM was the only factor predicting HF hospitalisation (HR = 0.6, 95% CI 0.42–0.79, P = 0.002).	Decreased
Shany, 2017 (Australia)	RCT	COPD	12	11 intervention; 18 control	72.1 ± 7.5 (Int); 74.2 ± 9.0 (control)	48% male (Int); 43% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Condition-specific	No statistically significant differences were demonstrated for the rate of ED presentations and hospitalisations. However, during the study, being in RPM group was associated with 20% relative reduction in the risk of admission and 14% relative reduction in the risk of ED presentation. Analysed as LOS per admission, there was no significant difference between the control and RPM patients.	No significant difference, though some relative reduction in risk
Sink, 2018 (USA)	RCT - except 17 non-randomised participants	COPD	8	83 intervention; 85 control	59.89 ± 1.09 (Int); 61.94 ± 1.07 (control)	34.9% males (Int); 37.6% males (control)	Smartphone	Manual	Passive	Not stated	Condition-specific	There were significantly fewer COPD-related hospitalisations in RPM group vs. control with 6 and 16, respectively. The absolute RR was 11.6% and the relative RR was 61.7%.	Decreased
Soriano, 2018 (Spain)	RCT	COPD	12	87 intervention; 82 control	71.5 ± 8.0 (Int); 71.3 ± 8.9 (control)	78.3% males (Int); 82.5% males (control)	Telephone	Manual	Passive	SMS	Condition-specific	Shorter mean LOS in RPM group (18.9 ± 16.1 days) compared to the control group (22.4 ± 19.5 days, P = 0.308). There were no statistically significant differences in primary efficacy analysis of the proportion of participants who had a severe exacerbation leading to a hospital admission or ED presentation over the 12-month period (60% in RPM vs. 53.5% in control, P = 0.321).	No significant difference
Srivastava, 2019 (USA)	Cohort	Heart failure	12	197 intervention; 870 control	73.4 (11.14) (Int); 75.4 (11.0) (control)	98.0% male (Int); 97.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	A significantly lower total admissions (1.1 vs. 1.6 admissions) and LOS (5.7 vs. 11.3 days) were seen in RPM group compared to the prior year (1.6 vs. 1.7, P<0.05; and 9.5 vs. 14 days, P<0.01, respectively). The RPM group also had a significantly lower LOS vs. control group (9.0 vs. 14.9, P<0.01). However, there was no significant difference in hospitalisations between the RPM group and control group (1.4 vs. 2.0, P<0.07). The number of ED presentations was not significantly different.	Decreased if looking pre-post, no significant difference compared to controls
Ten Eyck, 2019 (USA)	Cohort	Heart failure	12	Different levels of "engaged" interventions 8907; 8907 control	73.0 (9.92) (Int); 73.68 (10.6) (control)	46.3% male (Int - engaged); 47.5% male (control - non-engaged)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Engaged members who used their Bluetooth-enabled scales an average of 25 or more days per month demonstrated significantly lower post-index acute IP medical service utilisation vs. control group members (P<0.0001). Conversely, engaged members who used their scales ≤ 9 days per month or 9.1 to 18 days per month had significantly higher post-index acute IP medical service utilisation vs. control group (P< 0.0001 and P = 0.008, respectively). Engaged members had a significantly shorter average LOS vs. non-engaged members (4.14 vs. 4.66 days; P< 0.0001).	Decreased

Thomason, 2015 (USA)	Cohort	Heart failure	3	80 intervention; 1276 control	83.75 (SD 8.61) (Int); 81.97 (SD 10.55) (control)	60% female (Int); 60.2% female (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	Control group had a 21% all-cause hospital readmission rate vs. RPM group who had a 10% all-cause readmission rate.	Decreased
Trucco, 2019 (Italy)	Cohort	Home-ventilated neuromuscular patients	14	48 intervention; 48 control	16.4 (8.9–22.1) (Int); 15 (9.2–21.5) (control)	62.5% males (Int); 75.0% males (control)	Dedicated RPM unit + peripheral devices	Both	Passive	Telephone, VC	Condition-specific	Hospitalisations were significantly reduced post-RPM patients when compared to pre-RPM (11 vs. 24, P = 0.04) and to controls (11 vs. 21, P = 0.03). Median LOS was significantly lower in RPM patients vs. controls (6 vs. 7 days, P = 0.03). ED presentations were significantly reduced during the RPM trial (from 12 to 2, P<0.05) while hospital admissions were not significantly lower during RPM compared with pre-RPM (from 12 to 9 P>0.05).	Decreased hospitalisations, LOS, ED
Udsen, 2017 (Denmark)	Cluster RCT	COPD	12	578 intervention; 647 control	69.55 (9.36) (Int); 70.33 (9.11) (control)	48.27% males (Int); 43.74% males (control)	Tablet + peripheral devices	Manual	Active	Not stated	Condition-specific	Mean (SE) = Hospital admissions: RPM 2756.1 (463.8) vs. usual care 2753.1 (458.9); ED presentations 343.4 (24.8) vs. usual care 278.3 (21.5); Resource use is consistently higher in the RPM group.	Increased
Vianello, 2016 (Italy)	RCT	COPD	12	181 intervention; 81 control	75.96 (6.54) (Int); 76.48 (6.16) (control)	72.2% males (Int); 73.1% males (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone (only home visit for event management)	All-cause and condition-specific	The hospitalization rate for COPD and/or for any cause was not significantly different in the two groups (IRR = 0.89, 95% CI 0.79–1.04, P = 0.16 and IRR = 0.91, 95% CI 0.75 – 1.04); p = 0.16, respectively). The readmission rate for COPD and/or any cause was, however, significantly lower in the RPM group vs. control (IRR = 0.43, 95% CI 0.19–0.98, P = 0.01 and 0.46, 95% CI 0.24–0.89, P =0.01, respectively). LOS was not significantly different in the two groups.	No significant difference
Wagenaar, 2019 (Netherlands)	RCT	Heart failure	12	150 intervention; 150 control	66.6 ± 11.0 (Int); 66.9 ± 11.6 (control)	75.3% males (Int); 72.7% males (control)	Website	Manual	Passive	Telephone, Website	All-cause and condition-specific	No difference in hospitalisations (RPM vs. UC, 57 vs. 66, HR = 0.85, 95% CI 0.59–1.21).	No significant difference
Walker, 2018 (UK, Estonia, Sweden, Spain, Slovenia)	RCT	COPD	9	154 intervention; 158 control	71.0 (66.0, 75.8) (Int); 71.0 (65.3, 76.0) (control)	65.6% males (Int); 66.5% males (control)	Tablet + peripheral devices	Manual	Passive	Telephone	Not specified	The average LOS for all cause hospitalisations was 4.0 (IQR:1.0 - 9.0) days for control group and 1.0 (IQR:1.0 - 6.7) day for RPM group (P = 0.045). Compared to control, RPM patients who were hospitalised during the trial (n=41 and 45, respectively) were less than half as likely to be re-hospitalised (IRR = 0.46, P = 0.017). There was no difference between groups in the rate of hospitalisation (0.79 vs. 0.99, P = 0.276).	Decreased LOS, no significant difference in hospitalisation
White-Williams, 2015 (USA)	Cohort	Heart failure	3	235 intervention; 91 control	77 (Int); 71 (control)	47.7% male (Int); 52.7% male (control)	Remote monitoring system/device (not specified)	Manual	Active	Telephone	Not specified	The results of the tests indicated that there was no statistical significant difference in ED presentations and hospital readmissions between usual care and RPM group (Pearson chi-squared = 0.518 and 0.086, respectively, P > .05).	No significant difference
Williams, 2016 (USA)	Case control	Heart failure	2	105 intervention; 210 control	NR	43.8% male (Int); 46.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Condition-specific	No significant associations between RPM and hospital readmissions, $\chi 2$ = (1, n = 210, p-value = 0.71, phi = 0.71).	No significant difference

CI = confidence interval; CIED: cardiovascular implantable electronic device; COPD = chronic obstructive pulmonary disease; CRT-D = cardiac resyncronisation therapy defibrillator; CV = cardiovascular; df= degrees of freedom; ED = emergency department; HF = heart failure; HR = hazard ratio; ICD= implantable cardioverter defibrillator; IQR = inter-quartile range; IRR = incidence rate ratio; LOS = length of stay; NS = not significant; OR = odds ratio; RCT = randomised controlled trial; RPM = remote patient monitoring; RR = risk ratio or risk reduction; SD = standard deviation

Supplementary Table 2. Participant vitals monitored by RPM device in each study

First author, Year	Patient Group or Disease	Comorbidities mentioned	BP	HR	SpO2	HbA1c	Weight	Temp	ECG	FEV1	Patient or informant questionnaires (e.g. symptoms)	Other
Celler, 2018	Chronic conditions (unspecified)	Yes	X	X	X			X	X	X		
Kenealy, 2015	Chronic conditions (unspecified)	Yes	X		X	X	X					
Orozco-Beltran, 2017	Chronic conditions (unspecified)	Yes	X		X	X	X			X		
Chatwin, 2016	Chronic lung disease (COPD and chronic respiratory failure)	Yes	X	X	X		X				X	
Ishani, 2016	CKD	Yes	X	X	X	X	X					
Ho, 2016	COPD	NS	X		X		X	X			X	Other "Vital signs" (NS)
Sink, 2018	COPD	NS									X	Breathing rating (better, worse, or same)
Achelrod, 2017	COPD	Yes			X					X	X	
Alshabani, 2019	COPD	Yes										Adherence - inhaler
Clarke, 2018	COPD	Yes	X		X		X	X			X	
Esteban, 2016	COPD	Yes		X	X			X			X	Activity + respiratory rate
Kessler, 2018	COPD	Yes										"Health status information"
McDowell, 2015	COPD	Yes	X	X	X						X	
Mirón Rubio, 2018	COPD	Yes	X	X	X							
Ringbæk, 2015	COPD	Yes			X		X			X	X	
Shany, 2017	COPD	Yes	X	X	X	X	X	X	X	X	X	
Soriano, 2018	COPD	Yes	X		X					X		Respiratory rate, Compliance - oxygen therapy
Udsen, 2017	COPD	Yes	X	X	X		X					
Vianello, 2016	COPD	Yes		X	X							
Walker, 2018	COPD	Yes	X	X	X			X				Respitartory measures (forced oscillation technique)
Bohingamu Mudiyanselage, 2019	COPD or Diabetes	Yes	X	X	X	X						
Nancarrow, 2016	Geriatric	Yes	X		X	X	X	X				Other "Vital signs" (NS)
Lanssens, 2017	Gestational hypertensive disorders	Yes	X				X					Activity
Lanssens, 2018	Gestational hypertensive disorders	Yes	X				X					Activity
Bingler, 2018	Heart disease - infants	NS			X		X					
Gingele, 2019	Heart failure	NS									X	
Hale, 2016	Heart failure	NS										Adherence - medication
Koehler, 2018	Heart failure	NS	X	X	X		X		X		X	
Nouryan, 2019	Heart failure	NS	X	X	X		X					
Thomason, 2015	Heart failure	NS	X	X	X		X				X	
White-Williams, 2015	Heart failure	NS									X	"Vital signs" (NS)
Agboola, 2015	Heart failure	Yes	X	X	X		X				X	
Amir, 2017	Heart failure	Yes										Lung fluid content
Böhm, 2016	Heart failure	Yes										Intrathoracic fluid

Boriani, 2017	Heart failure	Yes											Lung fluid content and atrial tachyarrhythmia
Comin-Colet, 2016	Heart failure	Yes	X	X			X				X		
Kalter-Leibovici, 2017	Heart failure	Yes	X	X			X						
Kao, 2016	Heart failure	Yes									X		"Vitals" (NS)
Koulaouzidis, 2019	Heart failure	Yes					X						
Kraai, 2016	Heart failure	Yes					X				X		
Kurek, 2017	Heart failure	Yes		X									ICD data - NS
Olivari, 2018	Heart failure	Yes	X	X	X		X		X				
Ong, 2016	Heart failure	Yes	X	X			X				X		
Pedone, 2015	Heart failure	Yes	X	X	X								
Pekmezaris, 2019	Heart failure	Yes	X	X	X		X						
Riley, 2015	Heart failure	Yes	X	X	X		X						
Sardu, 2016	Heart failure	Yes		X									ICD data - NS
Srivastava, 2019	Heart failure	Yes	X	X	X		X						
Ten Eyck, 2019	Heart failure	Yes					X				X		
Wagenaar, 2019	Heart failure	Yes	X	X			X						
Williams, 2016	Heart failure	Yes	X	X	X		X						
Davis, 2015	HF, COPD	Yes		X	X		X						
Lyth, 2019	HF, COPD	Yes									X		Intake - medication
Martin-Lesende, 2017	HF, COPD or other chronic lung disease	Yes	X	X	X		X				X		Respiratory rate
Trucco, 2019	Home-ventilated neuromuscular patients	Yes		X	X								IPAP, EPAP, breathing patterns
De Luca, 2016	Nursing home patients; Mental health	Yes	X		X				X				
McElroy, 2016	Patients post surgery (cardiac)	Yes	X	X	X		X				X		
Rosner, 2018	Patients post surgery (orthopaedic)										X		
De Simone, 2019	Patients with CIEDs (AF)	Yes		X									Heart rhythm, device functioning, arrhythmic episodes
Geller, 2019	Patients with CIEDs (HF)	NS		X					X				Heart rhythm, device functioning
Hansen, 2018	Patients with CIEDs (HF)	NS		X					X				Heart rhythm, device functioning
Capucci, 2017	Patients with CIEDs (HF)	Yes		X									Heart rhythm, device functioning
Heidbuchel, 2015	Patients with CIEDs (unspecified)	NS		X					X				Heart rhythm, device functioning
Ricci, 2017	Patients with CIEDs (unspecified)	NS											ICD data - NS
Akar, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Amara, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning, atrial tachyarrhythmia
Buchta, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Bulava, 2016	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
D'Ancona, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
De Simone, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning

Ladapo, 2016	Patients with CIEDs (unspecified)	Yes		X									Cardiac monitoring - (NS)
Lu¨thje, 2015	Patients with CIEDs (unspecified)	Yes											Fluid index
Piccini, 2016	Patients with CIEDs (unspecified)	Yes											ICD data - NS (e.g. Heart rhythm, device functioning, arrhythmias)
Lew, 2018	Peritoneal dialysis patients	Yes	X				X						
Flaherty, 2017	Schizophrenia	NS										X	
TOTALS			**35**	**43**	**34**	**6**	**33**	**7**	**8**	**6**	**24**		

AF = atrial fibrillation; BP = blood pressure; CIED: cardiovascular implantable electronic device; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; ECG = electrocardiogram; EPAP = expiratory positive airway pressure; FEV1 = forced expiratory volume-one second; HbA1c = glycated haemoglobin; HF = heart failure; HR = heart rate; ICD= implantable cardioverter defibrillator; IPAP = inspiratory positive airway pressure; NS = not stated; SpO2= oxygen saturation

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMAreporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
Title			
	#1	Identify the report as a systematic review, meta-analysis, or both.	1
Abstract			
Structured	#2	Provide a structured summary including, as applicable:	2

summary		background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Introduction			
Rationale	#3	Describe the rationale for the review in the context of what is already known.	3
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
Methods			
Protocol and registration	#5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	3
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	4
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last	3

		searched.	
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	4
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	5
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	5-6
Planned methods of	#14	Describe the methods of handling data and combining results of studies, if done, including measures of	5-6

analysis		consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	n/a but mention this bias on p.10
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
Results			
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	Supplementary Table 1
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	8
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	Supplementary Table 1
Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	6-8

Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	n/a but mention this bias on p.10
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	6-11
Discussion			
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers	8-10
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	10
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	10
Funding			
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	11

BMJ Open

Does remote patient monitoring reduce acute care use? A systematic review

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-040232.R1
Article Type:	Original research
Date Submitted by the Author:	23-Dec-2020
Complete List of Authors:	Taylor, Monica ; University of Queensland, Centre for Online Health, Centre for Health Services Research Thomas, Emma; University of Queensland Centre for Online Health, Centre for Online Health, Centre for Health Services Research Snoswell, Centaine; University of Queensland Centre for Online Health, Centre for Health Services Research Smith, Anthony; The University of Queensland, Centre for Online Health, Centre for Health Services Research Caffery, Liam; The University of Queensland, Centre for Online Health, Centre for Health Services Research
Primary Subject Heading:	Health services research
Secondary Subject Heading:	Patient-centred medicine
Keywords:	HEALTH SERVICES ADMINISTRATION & MANAGEMENT, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Telemedicine < BIOTECHNOLOGY & BIOINFORMATICS

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Does remote patient monitoring reduce acute care use? A systematic review

Ms Monica Taylor[1] – ORCiD 0000-0001-5333-2955
Dr Emma E Thomas[1] – ORCiD 0000-0001-8415-0521
Dr Centaine L Snoswell[1] – ORCiD 0000-0002-4298-9369
Professor Anthony C Smith[1] – ORCiD 0000-0002-7756-5136
Associate Professor Liam J Caffery[1] – ORCiD 0000-0003-1899-7534

1. Centre for Online Health, Centre for Health Services Research, The University of Queensland, Brisbane, Australia.

Corresponding author:
Associate Professor Liam Caffery
Ground Floor, Building 33, Princess Alexandra Hospital
Woolloongabba QLD 4102
Australia
l.caffery@uq.edu.au

Word Count: 3950

What is the key question?
Does the use of remote patient monitoring reduce acute care (hospital admission, length of stay and emergency department presentations) use?
What is the bottom line?
Remote patient monitoring for patients with cardiovascular disease and / or COPD resulted in reduced acute care use in nearly half of interventions and no change in the remaining interventions.
Why read on?
Previous studies of RPM and their impact on acute health services have largely focussed on heart failure populations and manual collection of biometric data. Remote monitoring technologies have improved to now include automatic data collection using implanted devices and the use of RPM for other disease conditions. We present a contemporary review of the effectiveness of RPM in the context of hospital admissions, length of stay and emergency department presentations.

Abstract

Objective: Chronic diseases are associated with increased unplanned acute hospital use. Remote patient monitoring (RPM) can detect disease exacerbations and facilitate proactive management, possibly reducing expensive acute hospital usage. Current evidence examining RPM and acute care use mainly involves heart failure and omits automated invasive monitoring. This study aimed to determine if RPM reduces acute hospital use.

Methods: A systematic literature review of Pubmed, EMBASE and CINAHL electronic databases was undertaken in July 2019 and updated in October 2020 for studies published from January 2015 to October 2020 reporting RPM and effect on hospitalisations, length of stay, or emergency department presentations. All populations and disease conditions were included. Two independent reviewers screened articles. Quality analysis was performed using the Joanna Briggs Institute checklist. Findings were stratified by outcome variable. Subgroup analysis was undertaken on disease condition and RPM technology.

Results: From 2,050 identified records, 91 studies were included. Studies were medium to high quality. RPM for all disease conditions was reported to reduce admissions, length of stay, and emergency department presentations in 49% (n=44/90), 49% (n=23/47), and 41% (n=13/32) of studies reporting each measure, respectively. Remaining studies largely reported no change. Four studies reported RPM increased acute care use. RPM of chronic obstructive pulmonary disease (COPD) was more effective at reducing emergency presentation than RPM of other disease conditions. Similarly, invasive monitoring of cardiovascular disease was more effective at reducing hospital admissions versus other disease conditions and non-invasive monitoring.

Conclusion: RPM can reduce acute care use for cardiovascular disease and COPD patients. However, effectiveness varies within and between populations. RPM's effect on other conditions is inconclusive due to limited studies. Further analysis is required to understand underlying mechanisms causing variation in RPM interventions. These findings should be considered alongside other benefits of RPM, including increased quality of life for patients.

Generic keywords: telehealth; telemedicine; telecare; remote monitoring; telemonitoring; in-home monitoring; hospitalization; length of stay
ScholarOne keywords: Telemedicine, Health Services Administration & Management, International health services

Strengths and limitations

- This systematic review was not limited by disease condition and gives an overall picture on the effect of remote patient monitoring on acute care hospital use.
- We have included sub-analyses and new evidence, particularly for COPD patients and monitoring using implanted devices.
- Due to heterogeneity of included studies we were unable to perform a meta-analysis.

Introduction

Many people find it challenging to self-manage complex and co-morbid conditions and identify warning signs of exacerbation. Healthcare providers often only become aware of a decline in an individual's condition once symptoms have become severe enough to require escalation to acute care. This scenario may be avoided by using remote patient monitoring (RPM).

RPM or telemonitoring refers to the recording and transmission of patient biometrics, vital signs, and/or disease-related data to a healthcare provider using information and communications technology.[1] RPM data are disease-specific and commonly include measurements like blood pressure, weight, heart rate, respiration rate, pulse oximetry, spirometry, temperature, blood glucose levels or specific symptoms.[2] Data can be collected automatically (e.g. by an implanted or wearable devices) or manually collected by the patient using peripheral devices and a transmission hub. RPM interventions for cardiovascular disease (CVD) can be either invasive or non-invasive. Invasive interventions involve direct measurement of biometric data, such as heart rate and pulmonary artery pressures by an implanted device, which are then transmitted to the healthcare provider. Examples of implanted devices include pacemakers which are used to regulate abnormal rhythms, and implantable cardioverter defibrillators (ICDs) which are used in patients at high risk of cardiac arrest (e.g. ventricular tachycardia or fibrillation).[3] Non-invasive interventions involve the transmission of data, such as bodyweight, blood pressure, or pulse oximetry[4] and are used commonly in patients that require long-term self-management support (e.g. patients with heart failure).[5] Review of transmitted data may be active, which occurs when a remote healthcare provider regularly reviews patient data. Alternatively, it may be passive when the healthcare provider is only alerted if data readings reach a pre-determined clinical threshold. Interventions resulting from an abnormal data reading or data indicative of a decline in condition may include telephone support, videoconsultation, or home visits.

Chronic diseases are associated with high rates of unplanned acute hospital use, even more so when the patient has co-morbid conditions.[6] This represents a substantial cost to the health system. For example, in Australia there are more than 748,000 potentially avoidable hospitalizations per year, of which nearly half (46%) were due to chronic conditions such as congestive cardiac failure, diabetes complications, chronic obstructive pulmonary disease (COPD) and angina.[7] Early detection and proactive management of chronic disease exacerbations may result in decreased costly acute hospital use. Previous studies have demonstrated that RPM can effectively alert a healthcare team to a decline in a persons' condition enabling issues to be resolved out of hospital thereby reducing the need for urgent hospital admissions.[8] Existing research shows that for RPM to be cost effective it needs to reduce acute hospital use.[9] There have been a number of disease specific reviews (such as heart failure) that have reported effect of RPM on acute hospital use, however this is often a secondary outcome.[5, 10-12] These reviews were largely published more than five years ago. Hence, there is limited evidence for the effect of RPM using newer technologies such as implanted devices and for other disease conditions.[13] The aim of this study is to provide a contemporary evidence synthesis that will determine if RPM can reduce acute hospital use.

Methods

In order to achieve the aims of this study we conducted a systematic review of publications from the last five years (2015-2020). Supporting our decision to examine research from the last five years only was a recent systematic review reporting 43% of remote monitoring studies were published from 2015 on, and over 60% of Oxford Level of Evidence 1 papers were published post-2015.[14] The protocol for our review was registered (registration number: CRD42020142523) with the Prospective Register of Systematic Reviews (PROSPERO).[15]

Search strategy

To identify relevant articles we conducted searches of three electronic databases: PubMed (MEDLINE)[1966-2020], EMBASE (OvidSP)[1974-2020], and CINAHL (EBSCOHost)[1982-2020]. Boolean search terms (Box 1) were developed with the assistance of a university librarian and used a combination of medical subject headings (MeSH) and keywords related to remote monitoring, telemedicine, and acute care utilization. Searches were first conducted in July 2019 and updated in October 2020.

("Hospitalization"[Mesh] OR "length of stay"[All Fields] OR ("hospitalization"[All Fields] OR "hospitalization"[MeSH Terms] OR "hospitalization"[All Fields]) OR admission[All Fields] OR presentation[All Fields])

AND

("Remote monitoring"[All Fields] OR "Remote patient monitoring"[All Fields] OR (Inhome[All Fields] AND monitoring[All Fields]) OR "In-home monitoring"[All Fields] OR "Home telehealth"[All Fields] OR Telemonitoring[All Fields] OR Telecare[All Fields])

AND

((Case Reports[ptyp] OR Clinical Study[ptyp] OR Clinical Trial[ptyp] OR Clinical Trial, Phase I[ptyp] OR Clinical Trial, Phase II[ptyp] OR Clinical Trial, Phase III[ptyp] OR Clinical Trial, Phase IV[ptyp] OR Comparative Study[ptyp] OR Controlled Clinical Trial[ptyp] OR Evaluation Studies[ptyp] OR Introductory Journal Article[ptyp] OR Journal Article[ptyp] OR Meta-Analysis[ptyp] OR Multicenter Study[ptyp] OR Observational Study[ptyp] OR Randomized Controlled Trial[ptyp] OR Validation Studies[ptyp])
AND English[lang])

Box 1 Example search strategy (PubMed)

Inclusion/exclusion criteria

We included primary, empirical studies including randomised controlled trials (RCTs), cohort studies, and case control studies that compared acute hospital use by patients undergoing RPM with those not remotely monitored, or studies that compared acute hospital use pre- and post- RPM. Acute hospital use for the purpose of this review is defined as hospital admissions (including readmissions), length of stay, and emergency department (ED) presentations. Patients could be monitored for any disease condition as long as the monitored data was sent to a clinician for review (i.e. self-monitoring was excluded) and the patient was monitored while outside of a hospital setting. A

variety of RPM technology was eligible for inclusion such as non-invasive peripheral measurement devices, invasive cardiac implantable electronic devices, and manual data entry using tablets, smartphones, or websites. Only English language articles where the full-text was available were included.

Interventions that did not involve a disease condition (e.g. those with a focus on monitoring physical activity) were excluded. Studies that used simulated or modelled data were excluded, as were reviews, non-experimental studies, conference abstracts, and commentaries.

Selection

Titles and abstracts were screened independently by two researchers (MT, MB) who were also blinded to each other's selections. Where necessary the full text was used to determine eligibility. A third researcher (CS, ET, or LC) decided on inclusion when consensus was not reached.

Data extraction

Data was extracted from the full text of the articles and recorded on a data extraction form. A description of data extraction variables can be found in Table 1. One author (MT) extracted the data and a second author (ET) validated the accuracy by checking a 20% random selection of the data.

Table 1 Extracted variables

Variable	Description
First Author	Surname of the first author of the publication
Year	Year of publication
Country	Country where research was conducted
Study Type	Study design as cohort, RCT, quasi-experimental, or case-control
Patient Group	Medical condition of study participants
Comorbidities	Whether or not the authors mentioned participants having comorbidities
Data being monitored	Patient vitals measured using remote monitoring (e.g. BP, heart rate, etc.)
Trial length	Length of time a patient was remotely monitored (number of months)
Sample size	Number of participants in the research, listed by intervention and control groups
Mean age	The average or mean age of the intervention and control groups as reported by authors
Gender split	Percentage of male and female participants in the study
RPM Device	Device used for remote monitoring (e.g. tablet, dedicated RM unit, etc.)
Data collection	Whether biometric data was collected manually or automatically
Data review	Whether biometric data was reviewed by clinical staff passively (e.g. there was an automated alert system) or actively (e.g. nurse checks dashboard each day)
Supplementary support mode	If support from clinical staff beyond event management or routine visits occurred, what was the mode of contact used
Outcome type	Whether the outcome reported was for all cause, condition-specific, both, or not specified
Outcome findings	Results of the investigation (significant or not significant increase or decrease in acute care use and effect size where available)
Summary	Overall summary of whether RM increased, decreased, or had no significant effect on acute care use in the study

Quality assessment

Quality of the included studies was assessed using The Joanna Briggs Institute (JBI) critical appraisal checklists.[16] This suite of checklists has individual templates based on study design. Specific checklists have different numbers of questions. The appropriate checklist was chosen using an algorithm for classifying study design.[17] To allow comparison across study design, the number of checklist items that received a "yes" was converted to a proportion of the total number of questions. Based on the "yes" proportions, studies were categorised as high (80% and over), medium (60-79%), or low (<60%) quality.

Two researchers (MT, ET) completed quality assessment on each article and scores were compared and consensus reached via discussion. When a publication reported outcomes both related and not related to acute case use, the quality assessment score was based on the measurement of the acute care use outcomes specifically. No articles were excluded from this review based on their quality score.

Analysis

Findings from included article were stratified by acute care use as admissions, ED presentations or length of stay. Findings were categorised by the author's conclusion on increased, decreased, or no change on acute hospital use. Changes in use that were not statistically significant were categorised as no change. Subgroup analysis was undertaken on disease condition and technology category permutations (i.e. invasive versus non-invasive).

Due to the heterogeneity in population groups, intervention designs and outcome measures findings were synthesized narratively. Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[18]

Results

Study selection

Ninety-one articles were included in this review. The results of each stage of search and selection process are shown in the PRISMA diagram (Figure 1).

[INSERT FIGURE 1]
Figure 1. PRISMA flow diagram of screening process and study selection

Study characteristics

Included studies were primarily conducted in Europe (n = 52, 57%), followed by the United States (n=26, 29%). Most studies were randomized controlled trials (RCTs) (n=45, 50%) or cohort studies (n=34, 37%), with nine quasi-experimental studies (10%) and three case-controls (3%).

The sample size of patients ranged from 25 [19] to 92,566 [20] with the majority of included studies (n=68, 75%) having a sample size of greater than 100 participants (intervention and control arms combined). Follow-up time was longer than six months in the majority of studies (n=62, 68%), however, 12% (n=11) had a follow-up time of three months or less. Thirty-two studies (35%)

included >70% male participants. Gender bias was commonly observed in many CVD trials despite similar numbers of deaths across both genders.[21, 22] All interventions, except one study on infants with heart disease, were targeted at adults. Acute hospital use was reported for all causes (n=18, 20%), only the remotely monitored condition (n=21, 23%), both the all cause and the disease-specific condition (n=30, 33%), or was not specified (n=22, 24%).

Characteristics of all included studies are summarized in Supplementary Table 1.

Intervention characteristics

Disease conditions

The patient populations in the included studies were mostly people with CVD (n=54, 59%), COPD (n=18, 20%) or co-morbid CVD and COPD (n=4, 4%). Of these, invasive monitoring was used for 22 studies and non-invasive monitoring was used in 30 studies. Remaining studies (n=15, 17%) had varying study populations including nursing home residents, patients with schizophrenia, peritoneal dialysis patients, inflammatory bowel disease, and individuals on home ventilation.

Remote monitoring processes

The most common biometrics that were remotely monitored were heart rate (n=52, 57%), blood pressure (n=49, 54%), weight (n=44, 48%), and oxygen saturation (n=39, 43%). Cardiac implantable electronic devices (CIEDs) (n=22, 24%) can enable automated transmission of data, monitor heart rhythm, alert if an arrhythmic episode occurs and check the device function.

A comparison of data being monitored in each study can be seen in Supplementary Table 2.

The non-invasive interventions (n=69, 76%) required manual data collection performed by the patient or support person. Clinical review of biometrics was evenly split between those that had passive review (i.e. automated alert) and those that had active data review (e.g. clinician logging into system to review patient data daily). Typically, manual data collection was actively reviewed by a nurse or other clinician once per day.

In all studies out-of-range biometrics triggered clinical communication. Some interventions involved supplementary services from staff, such as assisting with education and health literacy. Modes of communication with patients included telephone (n=37, 41%), videoconference (n=13, 14%), and asynchronous methods such as SMS or email (n=10, 11%).

Technology

The technology for RPM was either a dedicated unit or hub (n=35, 39%); CIEDs including ICDs, cardiac resynchronization therapy (CRT) including those with defibrillators (CRT-Ds), and pacemakers (n=22, 24%); tablet computers application (n=13, 14%); or telephone or smartphone app (n=9, 10%); websites (n=4, 4%); or other technologies such as an electronic health diary, inhaler, or medication device (n=8, 9%). Forty studies explicitly stated the patient used peripheral devices such as weight scales, pulse oximeters, and thermometers.

Effect of remote monitoring on acute care use

RPM for all disease conditions was reported to have reduced admissions, length of stay and ED presentations in 49% (n=44 of 90), 49% (n=23 of 47), and 41% (n=13 of 32) of studies respectively for studies that reported each measure of acute care use. The remaining studies largely reported no change in acute care use for remotely monitored patients. A very small number of studies reported

RPM increased acute care use (Figures 2, 3, 4). The majority of studies set a significance level of 5% for concluding that there was a difference between groups, however individual study details on this can be viewed in Supplementary Table 1.

[Insert Figure 2]
Figure 2. Effect of RPM on hospitalisation by condition type

[Insert Figure 3]
Figure 3. Effect of RPM on length of stay by condition type

[Insert Figure 4]
Figure 4. Effect of RPM on ED presentations by condition type

CVD invasive

CVD using invasive monitoring appears to be most effective at reducing hospitalizations (Figure 2). Eleven RCTs have been conducted.[23-33] Of these, only three demonstrated a significant reduction in acute care use with a reduction in length of hospital stays[24] by 2.5 days (RPM = 10.3 ± 8.1 days, median: 8.0 days vs. non-monitored group = 17.5 ± 19.9 days, median 10.5 days, p = 0.027) and lower hospitalisation rates in the monitored group (37.1% vs 45.5%, p = 0.045;[29] hazard ratio 0.6, 0.42-0.79, p=0.002[33]). All remaining RCTs (n=6, 55%) showed no significant effect. Of the eight cohort studies conducted with invasive monitoring, five (63%) showed a significant reduction in hospital use. Two of these[20, 34] had very large sample sizes with matched controls (n=37,742 and 92,566 respectively). In fact, Piccini et al. [20], had a larger sample size (n=92,566) than all the other CVD invasive populations combined (n=49,113). Both Piccini et al. [20] and Akar et al. [34] reported an 18% lower risk of all-cause hospitalization in the RPM groups with both studies reporting identical adjusted hazard ratios of 0.82 (95% CI: 0.80 – 0.84; p-value: <0.001). Piccini et al. [20] also reported a shorter mean length of hospital stay of approximately three days (5.3 days vs. 8.1 days; P<0.001). These reductions were preserved for all implanted device types (pacemakers, ICDs and CRT) but were maximal in CRT participants. By contrast Ladapo et al.[35] reported the most pronounced benefits of hospital use in patients with ICDs.

CVD non-invasive

Most RCTs investigating the impact of non-invasive RPM were for heart failure populations (n=15, 37%). Findings from these studies have been mixed with eight trials (53%) reporting no difference and seven trials (47%) reporting a reduction in acute hospital use. The largest RCT included in this review reported the RPM group spent approximately two days less in hospital compared to control participants (RPM group = mean 3.8 days per year, 95% CI: 3.5–4.1 vs 5.6 days per year 95% CI: 5·2–6·0).[36] However, similarly large RCTs reported no change in the number of hospitalizations or length of stay.[37, 38] Studies varied in regard to the precise population investigated, the duration of RPM, the type of devices used, and the intensity and timing of the interaction. Koehler et al. provided the first structured RPM intervention that used a holistic approach including multiple healthcare providers (e.g. cardiologist, GP, nurse) and tailored support using a predefined algorithm.[36]

COPD

RPM of COPD appears to be most effective at reducing ED presentations (Figure 4). Of the 13 RCTs investigating RPM in COPD populations, seven trials (54%) showed no significant difference in hospital use between the intervention and control groups and approximately 30% reported a

reduction in hospital use. Two reported an increase in hospital admissions in the RPM group;[39,40] Udsen et al.[40] had the largest sample size (n=578/647 intervention/control) of the trials. Across the RCTs, COPD-related hospitalizations differed from a mean difference of ten fewer admissions in the intervention group of Sink et al.[41] over eight months (absolute risk reduction=11.6%; RPM = 6 hospitalizations vs. non-monitored = 16 hospitalizations) to a slight increase in admissions over a six month period (RPM admissions = 0.63 vs. 0.32 in non-monitored mean difference: 0.32, p-value: 0.026). [39] All cohort studies (n=9) reported a reduction in at least one measure of acute hospital use. Of these the largest sample size (n=651/7047 intervention/control) and over a 12-month period reported a lower proportion of patients hospitalized due to all-causes (−15.16%, $p < 0.0001$), and COPD-specific admissions (−20.27%, $p < 0.0001$). [42] On average, people in the RPM group spent 3.1 ($p < 0.0001$) and 2.07 ($p < 0.001$) fewer days in hospital due to all causes and COPD, respectively, than the control group.

Other conditions

The current RPM literature to date is dominated by adult CVD and COPD populations. It is worth noting that beneficial effects of RPM have been observed in some other conditions. Notably, one study demonstrated a significant reduction in hospital admission among infants with single ventricular heart disease (relative risk of hospital use in the control group: 2.19, 95% CI: 1.16-4.12, P = .016). [43] Reductions in hospital use were also seen in RPM groups with multiple chronic conditions ;[44] mental health; [45,46] and patients with home-ventilated neuromuscular conditions.[47]

Study quality

The overall quality of studies as assessed by the Joanna Briggs Institute critical appraisal checklists was medium to high (Figure 5).[16] The quality of RCTs was most often compromised by participant outcomes being assessed by someone who was not blinded to the control or intervention group. However, it can be challenging to blind an assessor or participant in this type of intervention. In cohort studies, the quality was compromised by incomplete follow. Only one third of the studies had clearly done so, while the remaining two thirds either did not address incomplete follow up or it was unclear.

[Insert Figure 5]

Figure 5. Number of articles by proportion of “Yes” responses to items on the Joanna Briggs Institute critical appraisal checklists, separated by study type

Discussion

Principal findings

This systematic review found around half of 91 included studies reported RPM decreased hospital admissions and around half reported no change. A smaller number of studies reported the effect of RPM on length of stay (n=47) and ED presentations (n=32), with around half reporting a decrease and half reporting no change for both of these measures of acute hospital use. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Similarly, invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease conditions and non-invasive monitoring. Only four studies reported higher acute hospital use resulting from RPM.[30, 39, 40, 48] Around 70% of included studies were for CVD, COPD or co-morbid CVD and COPD. RPM for lesser studied populations including mental health and neuromuscular conditions, appears feasible but findings on acute hospital use is inconclusive due to the limited

number of studies. Study quality as appraised by the JBI critical appraisal checklist was considered medium to high.

A strength of this study when compared to other reviews was the inclusion of all disease conditions, monitoring types and study designs. The broad inclusion categories has allowed analysis of RPM on disease conditions beyond those published on heart failure, previously excluded studies (e.g. cohort studies), and comparison of effectiveness of different RPM interventions. Whilst RCTs are considered the gold-standard experimental design, restricting to RCTs excludes large scale cohort studies, which can provide both strong evidence and are more applicable to real-world settings. For example, the Parthiban et al. [3] meta-analysis is, to the best of our knowledge, the only review that reports the impact on hospital admissions resulting from invasive cardiac monitoring. This study found no significant reduction in admissions, however, findings from a large scale cohort study (n=34,259/58,307 intervention/control) by Piccini et al.[20] found that invasive cardiac monitoring significantly reduced both all-cause hospitalizations and the resultant length of stay

A previous review of RPM for COPD populations included six primary studies (both RCTs and other study designs) of which four reported reduction in hospital admissions.[13] Our review included 22 studies on RPM of COPD and co-morbid COPD populations. Our findings were consistent when comparing the effect on hospital admissions. However, in addition we found a reduction in ED presentations in around half of the studies. Two of the four studies that reported RPM resulted in increased acute care use were in COPD population. This increase may explained by the perception that predicting COPD exacerbations based on variations in spirometry and other physiological measures continues to be a challenge resulting in high rates of false positive warnings in this cohort.[42]

Implications for practice

Effect of RPM on sub-populations

Clinical outcomes for patients on remote monitoring have been more effective for sub-populations when compared to the whole of population. The largest study to date, [20] reported that RPM was associated with reductions in all-cause hospitalization. While this association held across all implanted devices, it was most evident for cardiac resynchronization therapy patients, suggesting that sicker patients are the most likely to benefit. Furthermore, the greater effectiveness of invasive RPM may result from the continuous generation of biometric measurements. Whereas, non-invasive monitoring produces intermittent measurements. The safety of implanted devices can also be checked remotely using RPM to identify any device or lead malfunctions earlier.[34] Notably, no study in this review reported adverse events related to patient safety. This review has also demonstrated that the way remote monitoring services are implemented are highly variable and intervention characteristics could be a determinant of outcomes. For example, patients using smartphone apps were shown to have better compliance to monitoring than those using a web page.[49]

Importance of a patient-centric approach

RPM interventions are complex and require careful patient selection along with appropriate technology that accurately alerts healthcare staff and results in a timely response. Additionally, how RPM might improve a patient's health literacy and self-efficacy to manage their condition is likely to be highly important.[50] Supportive of this theory is one author who postulated this was due to participants becoming dependant on the RPM systems and telemonitoring nurse rather than developing the appropriate skills to self-manage. [51] A patient-centred approach that enables seamless interaction between patients and the healthcare system is likely to influence RPM success. This is demonstrated well by the comprehensive approach Koehler et al. [36] took by involving

multiple healthcare providers (e.g. cardiologist, GP, nurse) and using an algorithm to tailor support to participants resulting in positive results for people with heart failure.

Many studies reported that RPM increased quality of life, improved the timeliness of atrial fibrillation detection and improved communication.[5, 12, 38, 52] Focusing on effect of acute care use, may result in overlooking ancillary benefits of RPM.

There appears to be a lack of studies for some highly prevalent chronic conditions such as diabetes. This may be explained by the fact that exacerbation of diabetes is less likely to result in acute hospital use relative to CVD or COPD; and therefore studies on the effect of remote monitoring of diabetes do not use acute hospital use as an outcome measure.

Limitations

Findings of this review should be interpreted in light of some limitations. First, publication bias is possible with selective reporting of studies with findings of reduced acute hospital use. The included studies were highly heterogeneous in terms of patient groups (e.g. co-morbidities), intervention (e.g. inclusion of educational component, invasive versus non-invasive monitoring, active versus passive review) and study differences (e.g. all-cause *versu*s disease-specific acute hospital use). This makes generalizability of findings difficult. Due to heterogeneity and inability to perform a meta-analysis we used proportion of studies reporting a decrease in acute hospital use as a measure of comparative effectiveness. Differences in the control population may also lead to very different rates of admissions and influence whether or not a significant effect is found. For example, Boriani et al. [32] compared two trials found that one year mortality in the control-arm of each trial differed by nearly a factor of two. Finally, a study that uses patient self-reported acute hospital use may be less rigorous than those that used a retrospective approach supported by activity data, due to patient recall bias. [53]

Future research

Further investigation is needed to identify sub-populations and intervention characteristics that will enhance the effectiveness of remote monitoring. Policy makers and funders also need to understand if remote monitoring is cost effective. It is important for implementation of RPM interventions to consider costs from a system perspective. It would be wrong to assume that reducing admissions reduces costs, as there is potential of increasing collateral health system usage (e.g. to outpatient care). Economic analysis is also needed to consider the cost of implementing and operating RPM interventions as opposed to only comparing the direct cost of acute care use.[54]

Conclusion

This review has shown that RPM of CVD and COPD can reduce hospital admissions, length of stay, and emergency presentation in around half of interventions and results in no change in acute care usage in the remaining. Increased acute care use was rarely reported. The effect of RPM for other disease conditions is inconclusive due to the limited number of studies in these areas. Clinical outcomes for patients on remote monitoring have been more effective for sub-populations when compared to the whole of population. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease conditions and non-invasive monitoring. This may be in part due to the ability of implantable devices to continuously monitor a person and automatically transmit data. Implantable devices have advanced ability to directly detect cardiac issues (e.g. atrial fibrillation) rather than relying on physiological signs (e.g. changes in weight or blood pressure) that

may or may not be due to the underlying cardiac condition. Further research is required to understand the underlying mechanisms causing such variation in RPM studies. Findings from this review should be considered alongside other benefits of RPM including increased quality of life and autonomy for patients.

Acknowledgements

The authors would like to thank Julie Hansen, Senior Librarian from UQ Library for her assistance in developing the search strategy for this systematic review. They would also like to thank Ms Maryama Bihi for her assistance in screening titles and abstracts.

Conflict of Interest Statement

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Funding

This research is conducted for the NHMRC Partnership Centre for Health System Sustainability (Grant ID #: 9100002) administered by the Australian Institute of Health Innovation, Macquarie University. Along with the NHMRC, the funding partners in this research collaboration are: The Bupa Health Foundation; NSW Ministry of Health; Department of Health, WA; and The University of Notre Dame Australia. Their generous support is gratefully acknowledged.

While the NHMRC, The Bupa Health Foundation, NSW Ministry of Health, Department of Health, WA and The University of Notre Dame Australia, have provided in-kind and financial support for this research, they have not reviewed the content and are not responsible for any injury, loss or damage however arising from the use of, or reliance on, the information provided herein. The published material is solely the responsibility of the authors and does not reflect the views of the NHMRC or its funding partners.

Contributorship Statement

This research was conceptualised by LC. MT, ET, CS, AS and LC contributed to the study design. Searches and data extraction were carried out by MT and ET under guidance from CS and LC. Data analysis was performed by MT, ET, and LC. Manuscript was drafted by MT, ET, and LC. Critical review of manuscript was undertaken by all authors. All authors approved the final manuscript.

Patient Involvement Statement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results.

Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

Data Availability Statement

All data relevant to the study are included in the article or uploaded as supplementary information.

References

1. The American Telemedicine Association. Telemedicine, Telehealth, and Health Information Technology 2006. Accessed: 3 December 2020. Available at: https://www.who.int/goe/policies/countries/usa_support_tele.pdf?ua=1
2. Malasinghe LP, Ramzan N and Dahal K. Remote patient monitoring: a comprehensive study. *Journal of Ambient Intelligence and Humanized Computing*. 2019; 10(1): 57-76.
3. Parthiban N, Esterman A, Mahajan R, et al. Remote monitoring of implantable cardioverter-defibrillators: a systematic review and meta-analysis of clinical outcomes. *Journal of the American College of Cardiology*. 2015; 65(24): 2591-600.
4. Vegesna A, Tran M, Angelaccio M, et al. Remote patient monitoring via non-invasive digital technologies: a systematic review. *Telemedicine and e-Health*. 2017; 23(1): 3-17.
5. Inglis SC, Clark RA, McAlister FA, et al. Which components of heart failure programmes are effective? A systematic review and meta-analysis of the outcomes of structured telephone support or telemonitoring as the primary component of chronic heart failure management in 8323 patients: abridged Cochrane review. *European journal of heart failure*. 2011; 13(9): 1028-40.
6. Hernandez C, Jansa M, Vidal M, et al. The burden of chronic disorders on hospital admissions prompts the need for new modalities of care: a cross-sectional analysis in a tertiary hospital. *QJM: An International Journal of Medicine*. 2009; 102(3): 193-202.
7. Australian Institute of Health and Welfare. Potentially preventable hospitalizations in Australia by small geographic areas. 2019. AIHW. Accessed. Available at: https://www.aihw.gov.au/reports/primary-health-care/potentially-preventable-hospitalisations/contents/overview
8. Landolina M, Perego GB, Lunati M, et al. Remote monitoring reduces healthcare use and improves quality of care in heart failure patients with implantable defibrillators: the evolution of management strategies of heart failure patients with implantable defibrillators (EVOLVO) study. *Circulation*. 2012; 125(24): 2985-92.
9. Seto E. Cost comparison between telemonitoring and usual care of heart failure: a systematic review. *Telemedicine and e-Health*. 2008; 14(7): 679-86.
10. Bashi N, Karunanithi M, Fatehi F, et al. Remote monitoring of patients with heart failure: an overview of systematic reviews. *Journal of medical Internet research*. 2017; 19(1): e18.
11. Conway A, Inglis SC, Chang AM, et al. Not all systematic reviews are systematic: a meta-review of the quality of systematic reviews for non-invasive remote monitoring in heart failure. *Journal of telemedicine and telecare*. 2013; 19(6): 326-37.
12. Purcell R, McInnes S and Halcomb EJ. Telemonitoring can assist in managing cardiovascular disease in primary care: a systematic review of systematic reviews. *BMC family practice*. 2014; 15(1): 43.
13. Bolton CE, Waters CS, Peirce S, et al. Insufficient evidence of benefit: a systematic review of home telemonitoring for COPD. *Journal of evaluation in clinical practice*. 2011; 17(6): 1216-22.
14. Farias FACd, Dagostini CM, Bicca YdA, et al. Remote Patient Monitoring: A Systematic Review. *Telemedicine and e-Health*. 2020; 26(5): 576-83.
15. PROSPERO International prospective register of systematic review. The impact of remote patient monitoring on acute hospital use. 2020. National Institute for Health Research,. Accessed. Available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=142523
16. Joanna Briggs Institute. Critical Appraisal Tools. 2020. University of Adelaide. Accessed. Available at: https://joannabriggs.org/ebp/critical_appraisal_tools
17. The National Institute for Health and Care Excellence (NICE) and the Scottish Intercollegiate Guidelines Network (SIGN). Algorithm for classifying study design for questions of effectiveness. Unknown year. Accessed: 22 April 2020. Available at: https://www.sign.ac.uk/assets/study_design.pdf

18. PRISMA. Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2015. Accessed. Available at: http://www.prisma-statement.org/
19. Hale TM, Jethwani K, Kandola MS, et al. A Remote Medication Monitoring System for Chronic Heart Failure Patients to Reduce Readmissions: A Two-Arm Randomized Pilot Study. *J Med Internet Res*. 2016; 18(5): e91.
20. Piccini JP, Mittal S, Snell J, et al. Impact of remote monitoring on clinical events and associated health care utilization: A nationwide assessment. *Heart rhythm*. 2016; 13(12): 2279-86.
21. Mehran R, Vogel B, Ortega R, et al. The Lancet Commission on women and cardiovascular disease: time for a shift in women's health. *The Lancet*. 2019; 393(10175): 967-8.
22. The Lancet. Cardiology's problem women. *The Lancet*. 2019; 393(10175): 959.
23. Amara W, Montagnier C, Cheggour S, et al. Early Detection and Treatment of Atrial Arrhythmias Alleviates the Arrhythmic Burden in Paced Patients: The SETAM Study. *Pacing and clinical electrophysiology : PACE*. 2017; 40(5): 527-36.
24. Bulava A, Ošmera O, Šnorek M, et al. Cost analysis of telemedicine monitoring of patients with implantable cardioverter-defibrillators in the Czech Republic. *Cor et Vasa*. 2016; 58(3): e293-e302.
25. Geller JC, Lewalter T, Bruun NE, et al. Implant-based multi-parameter telemonitoring of patients with heart failure and a defibrillator with vs. without cardiac resynchronization therapy option: a subanalysis of the IN-TIME trial. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2019; 108(10): 1117-27.
26. Hansen C, Loges C, Seidl K, et al. INvestigation on Routine Follow-up in CONgestive HearT FAilure Patients with Remotely Monitored Implanted Cardioverter Defibrillators SysTems (InContact). *BMC cardiovascular disorders*. 2018; 18(1): 131.
27. Heidbuchel H, Hindricks G, Broadhurst P, 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. *European heart journal*. 2015; 36(3): 158-69.
28. Luthje L, Vollmann D, Seegers J, et al. A randomized study of remote monitoring and fluid monitoring for the management of patients with implanted cardiac arrhythmia devices. *Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology*. 2015; 17(8): 1276-81.
29. Tajstra M, Sokal A, Gadula-Gacek E, et al. Remote Supervision to Decrease Hospitalization Rate (RESULT) study in patients with implanted cardioverter-defibrillator. *EP Europace*. 2020; 22(5): 769-76.
30. Zakeri R, Morgan JM, Phillips P, et al. Impact of remote monitoring on clinical outcomes for patients with heart failure and atrial fibrillation: results from the REM-HF trial. *European journal of heart failure*. 2020; 22(3): 543-53.
31. Böhm M, Drexler H, Oswald H, et al. Fluid status telemedicine alerts for heart failure: A randomized controlled trial. *European heart journal*. 2016; 37(41): 3154-63.
32. Boriani G, Da Costa A, Quesada A, 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.
33. Sardu C, Santamaria M, Rizzo MR, et al. Telemonitoring in heart failure patients treated by cardiac resynchronisation therapy with defibrillator (CRT-D): the TELECART Study. *International journal of clinical practice*. 2016; 70(7): 569-76.
34. Akar JG, Bao H, Jones PW, et al. Use of Remote Monitoring Is Associated With Lower Risk of Adverse Outcomes Among Patients With Implanted Cardiac Defibrillators. *Circulation Arrhythmia and electrophysiology*. 2015; 8(5): 1173-80.

35. Ladapo JA, Turakhia MP, Ryan MP, et al. Health Care Utilization and Expenditures Associated With Remote Monitoring in Patients With Implantable Cardiac Devices. *The American journal of cardiology*. 2016; 117(9): 1455-62.
36. Koehler F, Koehler K, Deckwart O, et al. Efficacy of telemedical interventional management in patients with heart failure (TIM-HF2): a randomised, controlled, parallel-group, unmasked trial. *The Lancet*. 2018; 392(10152): 1047-57.
37. Kalter-Leibovici O, Freimark D, Freedman LS, et al. Disease management in the treatment of patients with chronic heart failure who have universal access to health care: A randomized controlled trial. *BMC Medicine*. 2017; 15(1).
38. Ong MK, Romano PS, Edgington S, et al. Effectiveness of Remote Patient Monitoring After Discharge of Hospitalized Patients With Heart Failure: The Better Effectiveness After Transition -- Heart Failure (BEAT-HF) Randomized Clinical Trial. *JAMA internal medicine*. 2016; 176(3): 310-8.
39. Chatwin M, Hawkins G, Panicchia L, et al. Randomised crossover trial of telemonitoring in chronic respiratory patients (TeleCRAFT trial). *Thorax*. 2016; 71(4): 305-11.
40. Udsen FW, Lilholt PH, Hejlesen O, et al. Cost-effectiveness of telehealthcare to patients with chronic obstructive pulmonary disease: Results from the Danish TeleCare North' cluster-randomised trial. *BMJ Open*. 2017; 7(5): e014616.
41. Sink E, Patel K, Groenendyk J, et al. Effectiveness of a novel, automated telephone intervention on time to hospitalisation in patients with COPD: A randomised controlled trial. *J Telemed Telecare*. 2018; 26(3): 132-9.
42. Achelrod D, Schreyogg J and Stargardt T. Health-economic evaluation of home telemonitoring for COPD in Germany: evidence from a large population-based cohort. *The European journal of health economics : HEPAC : health economics in prevention and care*. 2017; 18(7): 869-82.
43. Bingler M, Erickson LA, Reid KJ, et al. Interstage Outcomes in Infants With Single Ventricle Heart Disease Comparing Home Monitoring Technology to Three-Ring Binder Documentation: A Randomized Crossover Study. *World Journal for Pediatric and Congenital Hearth Surgery*. 2018; 9(3): 305-14.
44. Celler B, Varnfield M and Jayasena R. What Have We Learned from the CSIRO National NBN Telehealth Trial? *Studies in health technology and informatics*. 2018; 2461-17.
45. De Luca R, Bramanti A, De Cola MC, et al. Tele-health-care in the elderly living in nursing home: the first Sicilian multimodal approach. *Aging clinical and experimental research*. 2016; 28(4): 753-9.
46. Flaherty LR, Daniels K, Luther J, et al. Reduction of medical hospitalizations in veterans with schizophrenia using home telehealth. *Psychiatry research*. 2017; 255153-5.
47. Trucco F, Pedemonte M, Racca F, et al. Tele-monitoring in paediatric and young home-ventilated neuromuscular patients: A multicentre case-control trial. *J Telemed Telecare*. 2019; 25(7): 414-24.
48. D'Ancona G, Safak E, Senges J, et al. Activation of remote monitoring for cardiac implantable electronic devices: small dog for tall weeds. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2017; 106(10): 833-9.
49. Schreier G, Eckmann H, Hayn D, et al. Web versus App - compliance of patients in a telehealth diabetes management programme using two different technologies. *Journal of Telemedicine and Telecare*. 2012; 18(8): 476-80.
50. Bohingamu Mudiyanselage S, Stevens J, Watts JJ, et al. Personalised telehealth intervention for chronic disease management: A pilot randomised controlled trial. *J Telemed Telecare*. 2019; 25(6): 343-52.
51. Agboola S, Jethwani K, Khateeb K, et al. Heart failure remote monitoring: evidence from the retrospective evaluation of a real-world remote monitoring program. *J Med Internet Res*. 2015; 17(4): e101.

52. Klersy C, De Silvestri A, Gabutti G, et al. Economic impact of remote patient monitoring: an integrated economic model derived from a meta-analysis of randomized controlled trials in heart failure. *European journal of heart failure*. 2011; 13(4): 450-9.
53. Nancarrow S, Banbury A and Buckley J. Evaluation of a National Broadband Network-enabled Telehealth trial for older people with chronic disease. *Australian Health Review*. 2016; 40(6): 641-8.
54. Peretz D, Arnaert A and Ponzoni NN. Determining the cost of implementing and operating a remote patient monitoring programme for the elderly with chronic conditions: A systematic review of economic evaluations. *Journal of telemedicine and telecare*. 2018; 24(1): 13-21.

Figures

Supplementary Information

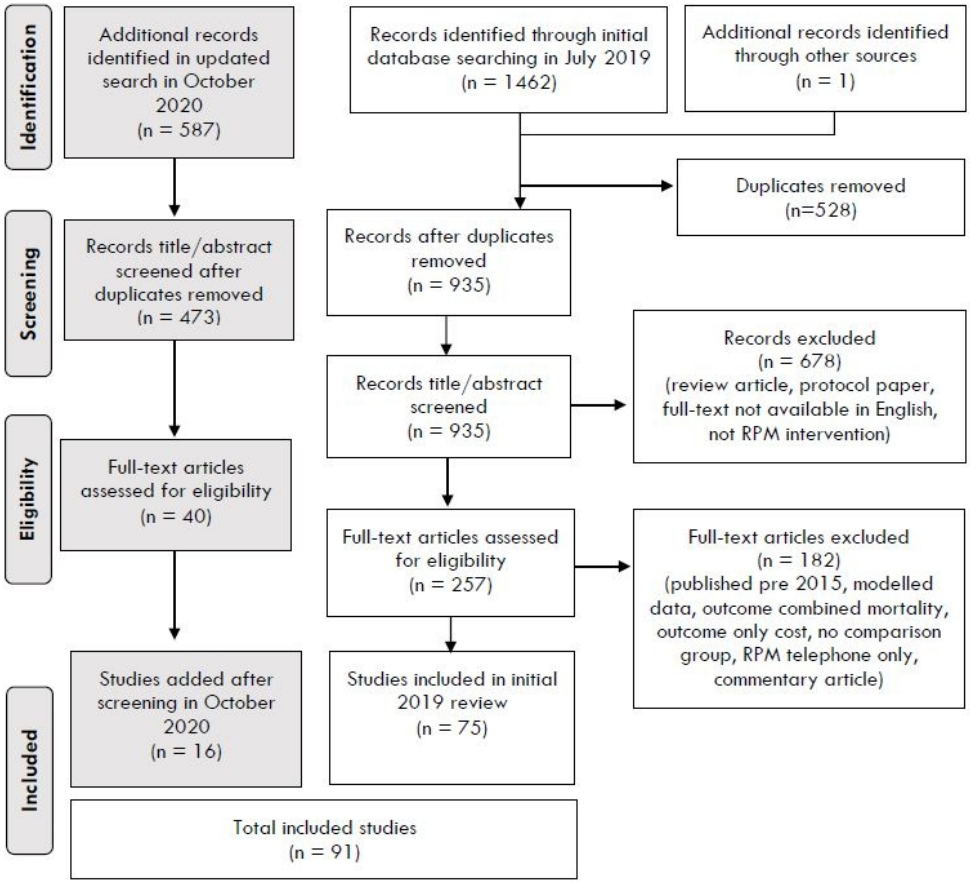

Figure 1. PRISMA flow diagram of screening process and study selection. (RPM= remote patient monitoring)

205x184mm (96 x 96 DPI)

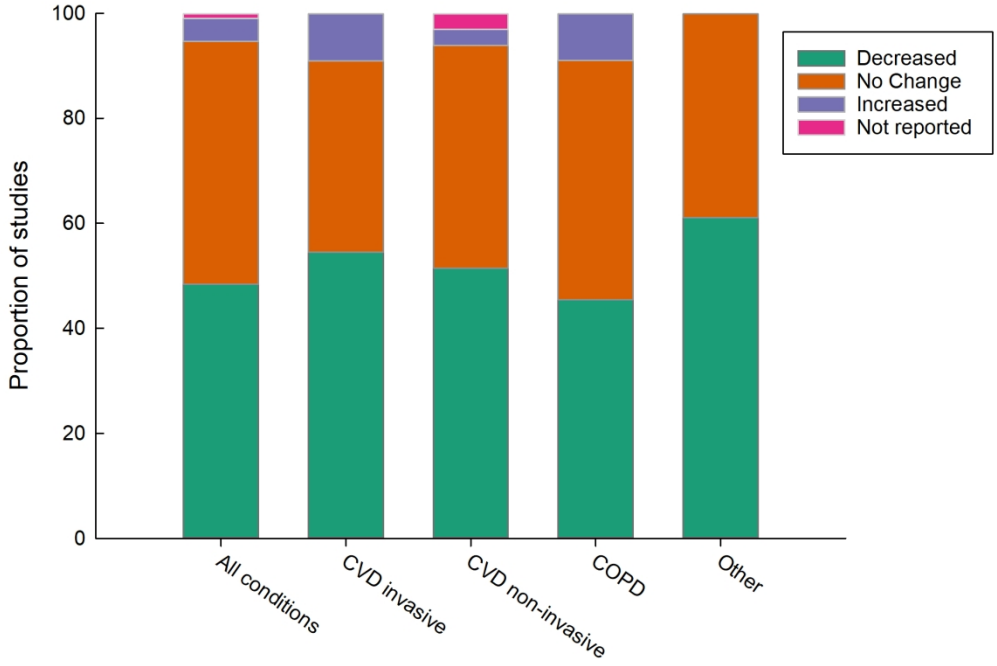

Figure 2. Effect of RPM on hospitalisations by condition type

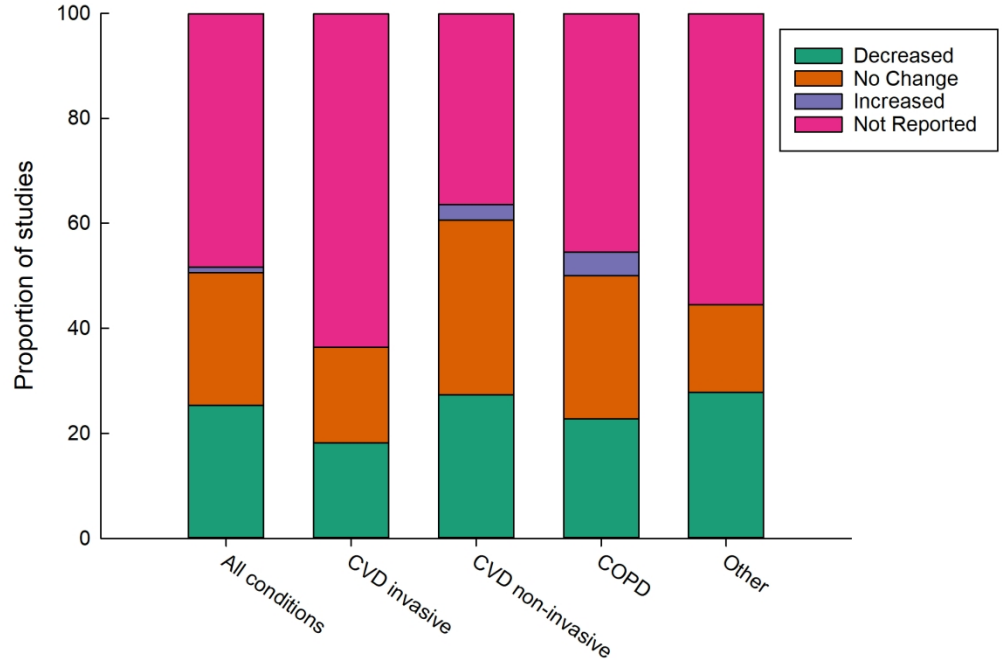

Figure 3. Effect of RPM on length of stay by condition type

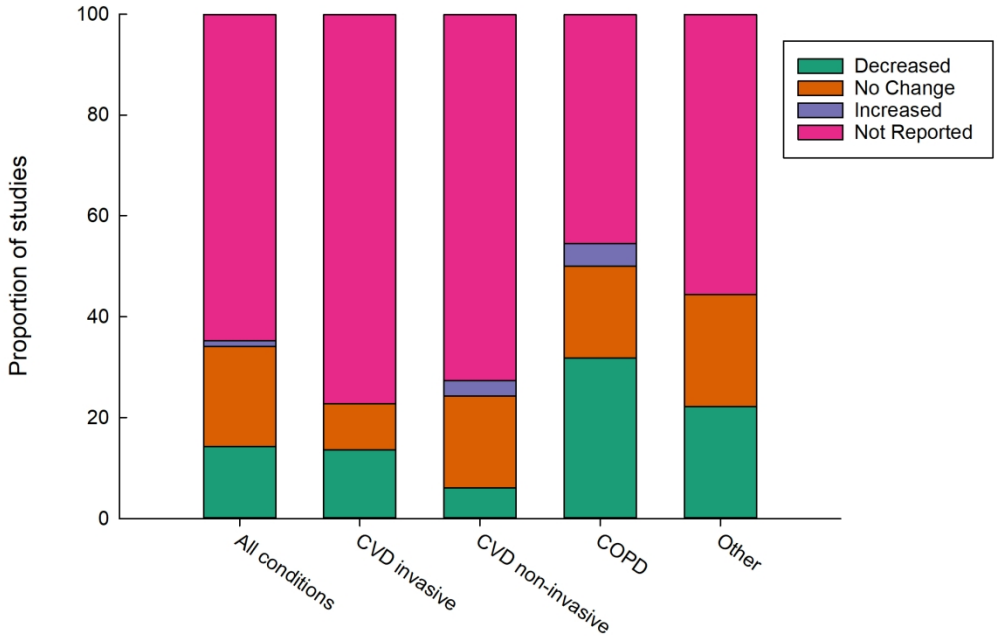

Figure 4. Effect of RPM on ED presentations by condition type

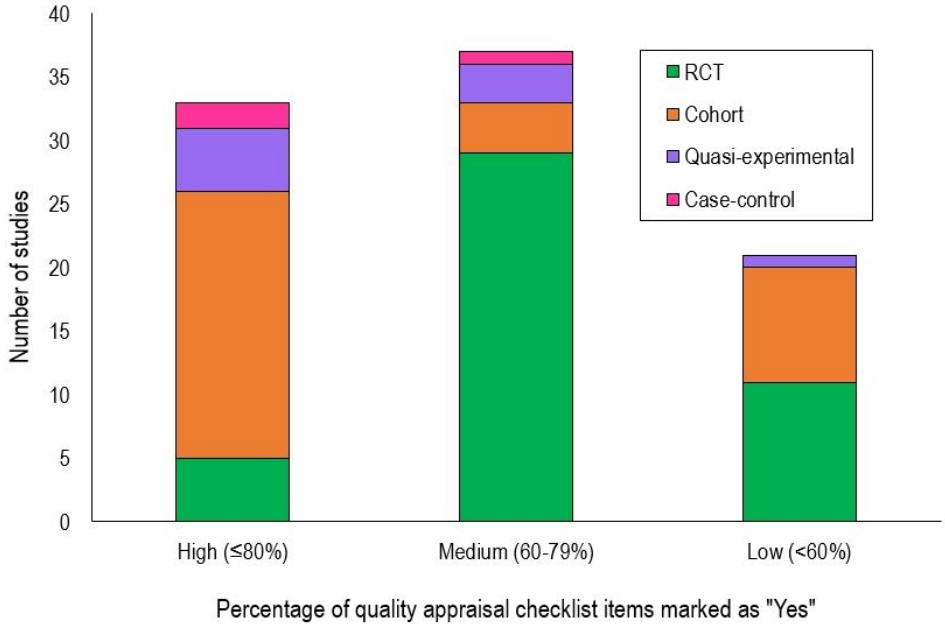

Figure 5. Number of articles by proportion of "Yes" responses to items on the Joanna Briggs Institute critical appraisal checklists, separated by study type

226x156mm (96 x 96 DPI)

Supplementary Table 1. Characteristics of included studies

First Author, Year (Country)	Study type	Patient group	Trial length (approx. months)	Sample size (close out if avail)	Average/Mean age	M/F split	RPM device	Data collection type	Data review type (Active, Passive - alert)	Supplementary support modes	OUTCOME: All cause, condition-specific, both, or not specified	Outcome findings as reported by authors in article	Summary of RPM effect on acute care use
Achelrod, 2017 (Germany)	Cohort	COPD	Baseline 24, Follow up 12	651 intervention; 7047 control	64.24 (Int); 69.47 (control before); 64.24 (control after)	43.93% female (Int); 49.17 (control before); 43.93 (control after)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	Hospitalisations due to all causes (-15.16 %, p<0.0001), due to COPD (-20.27 %, p<0.0001) and COPD-related ED presentations (-17.00 %, p<0.0001) were consistently lower in RPM patients, leading to fewer all-cause (-0.21, P<0.0001), COPD-related (-0.18, p\0.0001) and COPD-related ED presentations (-0.14, P<0.0001). On average, people in RPM group spent 3.1 (P<0.0001) and 2.07 (P<0.001) fewer days in hospital due to all causes and COPD, respectively, than control group.	Decreased
Agboola, 2015 (USA)	Cohort	Heart failure	4	174 intervention; 174 control	76.66 (10.71 SD) (Int); 76.76 (10.71 SD) (control)	58.62% male (Int & control)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Compared with controls, hospitalisation rates decreased within first 30 days of program enrollment (HR = 0.52, 95% CI 0.31-0.86, P=.01); Mean LOS similar in both groups (7 (8.92) RPM vs. 8 (8.83) control, P = 0.92).	Decreased hospitalisation, no significant difference in LOS
Akar, 2015 (USA)	Cohort	Patients with CIEDs (unspecified)	6	20852 intervention; 16890 control	67.5 (SD 12.1, 21-89) (Int); 66.5 (SD 13.0, 21-89) (control)	70.9% male (Int); 72.6% male (control)	CIED	Automatic	Passive	Not stated	All-cause	Risk of rehospitalisation of RPM patients (n=9150, 60%) lower than those not using RPM (HR= 0.82, 95% CI 0.80–0.84, P<0.0001).	Decreased
Alshabani, 2019 (USA)	Cohort	COPD	12	39	68.6 (9.9)	M:F 20:19	Electronic inhaler monitoring device	Automatic	Passive	Not stated	All-cause and condition-specific	RPM associated with reduction in COPD-related ED presentations and hospitalisations combined per year - 2.2 (± 2.3) vs. 3.4 (± 3.2), p=0.01. All-cause this was also was reduced, although difference was NS (3.4 (2.6) vs. 4.7 (4.1), P = 0.06).	Decreased condition-specific, no significant difference all-cause
Amara, 2017 (France)	RCT	Patients with CIEDs (unspecified)	12	291 intervention; 304 control	79 (±8) (all, Int, and control)	63% male (all); 64% male (Int); 61% male (control)	CIED	Automatic	Passive	Not stated	Condition-specific	In RPM group, 39 patients (13.4%) had CV-related hospitalisations vs. 42 patients (13.8%) in control group (NS); Mean LOS was 10 ± 14 days in the RPM vs. 11 ± 13 days in the control group (NS).	No significant difference
Amir, 2017 (Israel)	Cohort	Heart failure	Varied - <12	50	73.8 ± 10.3	62% male	Dedicated RPM unit + peripheral devices	Automatic	Passive	Not stated	Condition-specific	The HR for hospital readmission rates between the pre-RPM period and the RPM period was 0.07 (95% CI 0.01–0.54, P = 0.01).	Decreased
Bingler, 2018 (USA)	RCT	Heart disease - infants	Few months	31	1.44 (0.80 to 2.13) (1 month group); 0.70 (0.47 to 1.43) (2 month group)	56.2% female (1 month grp); 26.7% female (2 month group)	Tablet	Manual	Both	Not stated	Not specified	Higher risk of having a high resource ultilisation admission in control than RPM group (RR = 2.19, 95% CI 1.16-4.12, P = 0.016); Total LOS per 100 interstage days was significantly lower with RPM vs usual care. Difference in admissions NS - RPM 26 (0.9) vs. control 19 (1.0) - P = 0.75; Total ED presentations (ED presentations per 100 interstage days) RPM 20 (0.7) vs. control 13 (0.7) (P = 0.96).	Decreased
Bohingamu Mudiyansela ge, 2019 (Australia)	RCT	COPD and/or Diabetes	12	86 intervention; 85 control	70.7 ± 11.56 (Int); 70.13 ± 13.26 (control)	60% male (Int); 47% male (control)	Tablet + peripheral devices	Manual	Both (out of hours alerts)	VC	Not specified	Lower mean acute hospital LOS over 12 months in RPM (4.6 vs. 8.7 days; 95% CI: -8.6 to -0.4); Difference in hospitalisations NS (proportion of participants who had at least one hospitalisation 53% vs. control 55%, P = 0.813).	Decreased LOS, no significant difference in hospitalisations
Böhm, 2016 (Germany)	RCT	Patients with CIEDs (HF)	~24	175 intervention; 167 control	66.1 ± 10.1 (Int); 66.4 ± 10.7 (control)	77.2% male (Int); 82.3% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific (condition-specific result reported)	The number of HF hospitalisations per patient per year 0.24 for the RPM group and 0.30 for the control (P = 0.20).	No significant difference
Boriani, 2017 (Various - Europe and Israel)	RCT	Patients with CIEDs (HF)	~24	437 intervention; 428 control	66 ± 11 (Int); 67 ± 10 (control)	78.8% male (Int); 73.1% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	ED presentations (not followed by hospitalisation) significantly lower in RPM (IRR = 0.72, 95% CI 0.53–0.98, P = 0.04); Burden of CV-related healthcare resource utilization was 38% lower in RPM vs. control (IRR = 0.62, 95% CI 0.58–0.66, P<0.001); All-cause hospitalisation rates, estimated as the 2-year rate per 100 patients, were 96 (95% CI 86–106) and 90 (95% CI 80–100, P = 0.83), respectively. CV-related hospitalisations were 197 (111 due to HF) and 200 (103 due to HF) in RPM and control, respectively.	Decreased ED but increased unscheduled visits
Buchta, 2017 (Poland)	Cohort	Patients with CIEDs (unspecified)	24	287 intervention; 287 control	61.94 (53.25 – 70.75) (Int); 62.80 (56.04 – 69.51) (control)	84% male (both)	CIED	Automatic	Passive	Not stated	All-cause	No reduction in the number of defined medical contacts. Hospitalisations (P=NS) in control vs. RPM, respectively, in year 1, 2, 3 hospitalisations Year 1= 1.4 vs. 1.16; Year 2 = 0.74 vs. 0.42; Year 3= 0.55 vs. 0.36.	No significant difference
Bulava, 2016 (Czech Republic)	RCT	Patients with CIEDs (unspecified)	26	97 intervention; 101 control	66 ± 11 (Int); 68 ± 12 (control)	83.5% male (Int); 78.2% male (control)	CIED + dedicated RPM unit	Automatic	Passive	Telephone	Not specified	LOS shorter in RPM group (10.3 ± 8.1 days, median: 8.0 days) vs. control group (17.5 ± 19.9 days, with median of 10.5 days, P = 0.027); 213 hospitalisations in total: 124 (58.2%) in control group and 89 (41.8%) in RPM group (P = 0.127).	Decreased

Capucci, 2017 (Italy)	Cohort	Patients with CIEDs (HF)	12	499 intervention; 488 control	66 (12) (Int); 65 (13) (control)	77% male (both)	CIED	Automatic	Passive	Not stated	Not specified	Rate of hospitalisations in first 12 months of follow-up was 0.16 and 0.27/year in RPM and control group, respectively (RR = 0.59; P = 0.004).	Decreased
Celler, 2018 (Australia)	Cohort	Chronic conditions (unspecified)	9	114 intervention; 173 control	71.1 (9.3) (Int); 71.9 (9.4) (control)	64% male (Int); 56% male (control)	Dedicated RPM unit	Manual	NS	Not stated (But said reminded to record vitals)	Not specified	RPM patients significant (P = 0.006) reduction in rate of hospitalisations vs. controls (P = 0.869); After one year of RPM average expected LOS reduced by almost 68% from predicted value of 24.6 to 7.9 days.	Decreased
Chatwin, 2016 (UK)	RCT	Chronic lung disease (COPD and chronic resp failure)	6	38 intervention; 34 control	61.8 (11.9)	48% male	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	Respiratory hospitalisations for acute exacerbations at 6 months increased in RPM group — frequency 0.32 control vs. 0.63 RPM (mean difference 0.32, P = 0.026). Although time to first admission did not change, actual hospitalisations doubled from 18 to 36.	Increased
Clarke, 2018 (UK)	Cohort	COPD	3 monitor, 12 pre data	227	70.9 ± 8.9	50% male	Dedicated RPM unit + peripheral devices	Manual	Active	RM unit message	All-cause and condition-specific	Average LOS decreased in one group from 11.5 in period 12 months before to 6.5 days during RPM; In other group average LOS decreased 7.5 to 5.2 days; For all other causes there was a reduction in LOS during RPM period vs. period 12 months before (9%) but an increase (10%) vs. period immediately before RPM; COPD hospitalisations increased from 64 to 71; Other hospitalisations decreased 43 to 39.	Decreased LOS, variability in hospitalisations, and changed if compared to immediate pre or 12 months pre.
Comin-Colet, 2016 (Spain)	RCT	Heart failure	6	81 intervention; 97 control	74 ± 11 (Int); 75 ± 11 (control)	43% female (Int); 39% female (control)	Tablet	Manual	Active	Telephone, VC	All-cause and condition-specific	HF readmission (HR = 0.39, CI 0.19–0.77, P = 0.007) and CV readmission (HR = 0.43, CI 0.23–0.80, P = 0.008) were reduced in RPM group; mean LOS significantly reduced in RPM group for all cause, HF and CV readmissions. In patients hospitalised, mean LOS tended to be shorter in RPM group. In adjusted models, results were similar.	Decreased
Cross, 2019 (USA)	RCT	Inflammatory bowel disease	12	231 intervention; 117 control	40.1 ± 13.2 (Every other week [EOW] cohort; 36.4 ± 11.5 (Weekly cohort); 40.1 ± 11.7 (control). All = 38.9 ± 12.3 yrs)	41.7% male (Int every two weeks); 43.1% male (Int weekly); 45.3% male (control); All = 56.6% female	Smartphone	Manual	Passive	SMS	All-cause and condition-specific	IBD-related hospitalisations increased in the control group from 14.7 to 16.4; however in the RPM EOW and RPM Weekly, IBD-related hospitalisations decreased from 24.3 to 14.4 and 24.1 to 9.8 respectively. The difference in IBD-related hospitalisation was significant for the RPM weekly group only (P = 0.04); Non-IBD related hospitalisations increased from 3.4 to 11.2 in controls and decreased from 5.5 to 0.9 and 5.4 to 2.7 in the RPM EOW and weekly cohorts respectively (P = 0.02 in RPM EOW and p = 0.04 in RPM weekly; Decrease in hospitalisations but increase in non-invasive diagnostic tests, telephone calls and electronic encounters.	Decreased
D'Ancona, 2017 (Germany)	Cohort	Patients with CIEDs (unspecified)	12	720 RM capable devices (91 activated); 503 control	68 (58-75) (Int); 67 (57-75) (control)	20% female (Int); 21.5% female (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM patients had higher re-hospitalisation rate (45.2% vs. 34.8%, P = 0.059).	Increased
Davis, 2015 (USA)	Cohort	HF, COPD	3	117 intervention; 233 control	COPD: 61 (11) (Int); 63 (15.8) (control) HF: 62 (16.6) (Int); 65 (14.6) (control)	COPD: 62.1% female (Int); 60.3% female (control) HF: 45.8% female (Int); 56% female (control)	Dedicated RPM unit	Manual	Passive	Telephone, Dedicated RM unit message	All-cause	30-day re-admissions were reduced 50% for both chronic disease cohorts vs. control (COPD, 10.3% vs. 21.8%, HF, 8.5% vs. 17%); 37% reduction in ED presentations in the 30-day postdischarge period for COPD cohort compared with control patients (6.9% vs. 10.9%), but 75% increase in ED presentations for the HF cohort (11.9% vs. 6.8%) in the 30 days after the index discharge; Admissions 150 to 49 in COPD but 50 to 52 in HF.	Decreased for COPD, increased ED and hospitalisations for HF
De Luca, 2016 (Italy)	RCT	Nursing home patients; Mental health	Not specified	32 intervention; 27 control	77 (71-80) (Int); 85 (79-89) (control)	34.4% male (Int); 29.6% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	VC	Not specified	Admission to health care service was higher (x^2 = 3.96, P<0.05) in control group (8/27) vs. RPM group (3/32).	Decreased
De Simone, 2015 (Italy)	Non-randomised controlled trial/Quasi-experimental	Patients with CIEDs (unspecified)	24	499 intervention; 488 control	66 ± 12 (Int); 66 ± 13 (control)	76% male (Int); 78% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	RPM reduced risk of all-cause hospitalisations (87 vs. 129; 0.15 vs. 0.28 events/ year; IRR = 0.54, 95% CI 0.41–0.71, P < 0.001) and CV hospitalisations (60 vs. 89; 0.11 vs. 0.20 events/year; IRR = 0.54, 95% CI 0.38–0.75, P < 0.001) vs. control group; LOS was 517 days (0.91 days/year) in RPM group and 974 days (2.15 days/year) in control group.	Decreased
De Simone, 2019 (Italy)	Cohort	Patients with CIEDs (AF)	12	26 intervention; 45 control	82 [79–87] (Int); 85 [78–89] (control)	34.6% female (Int); 53.3% female (control)	CIED	Automatic	Passive	Not stated	All-cause	All-cause hospitalisations were 33, with lower event rate in RPM group vs. control (5.8; 95% CI 3.3–9.4 vs. 9.7; 95% CI 6.5–13.9 per 100 patient-months; P = 0.027); RR with RPM was significant for all-cause hospitalisation (RR= 0.44, 95% CI 0.21–0.93).	Decreased

Esteban, 2016 (Spain)	Cohort	COPD	24	120 intervention; 78 control	71.34 (Int); 70.1 (control) ALL: 70.83	86.6% male (Int); 87.2% male (control); All: 86.8% male	Smartphone	Manual	Active	Telephone	Condition-specific	After 2 years, both cohorts showed reduction in rate of hospitalisations (P<0.001) but reduction was significantly higher in RPM group (1.14 vs. 2.33, P<0.001); Significant differences in rate of ED presentations (pre-post = 0.4 (0.1–0.6) P = 0.006), cumulative LOS, and rate of 30-day readmission during study period; In multivariate analysis, being in the RPM group was independently associated with lower rates of hospitalisations (IRR = 0.38, 95% CI 0.27–0.54, P<0.0001), ED presentation (IRR = 0.56, 95% CI 0.35–0.92, P<0.02), and 30-day readmission (IRR = 0.46, 95% CI 0.29–0.74, P<0.001), as well as cumulative LOS (IRR = 0.58, 95% CI 0.46–0.73, P<0.0001).	Decreased
Flaherty, 2017 (USA)	RCT	Schizophrenia	3	20 intervention; 25 control	49.9 ± 12.7 (Int); 51.2 ± 11.1 (control)	90% male (Int); 96% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Not specified	RPM group significantly less likely vs. control group to have at least one hospitalisation (5.0% vs. 32.0%, P<0.05). Also, RPM group had significantly lower average number of hospitalisations (0.10 ± 0.45 vs. 0.60 ± 1.19, Mann Whitney U=4.67, df=1, P<0.05). RPM group also had significantly lower mean LOS (0.70 ± 3.13 vs. 2.56 ± 6.11, Mann Whitney U,=4.59, df=1, P<0.05). No significant differences were found between groups in terms of numbers of psychiatric hospitalisations (0.65 ± 1.04 vs. 0.52 ± 0.77). Additionally, RPM and control groups did not differ on ED presentations (0.60 ± 1.23 vs. 0.92 ± 1.19).	Decreased hospitalisations, no significant difference on ED
Galinier, 2020 (France)	RCT	Heart failure	18	305 intervention; 327 control	70.0±12.4 (Int); 69.7±12.5 (Control)	73.4% male (Int); 71.0% male (control)	Electronic scales + Dedicated RPM unit	Manual	Passive	Telephone	All-cause and condition-specific	Mean±SD number of unplanned hospitalisations for HF was 0.59±1.26 for telemonitoring and 0.75±1.42 for SC (rate ratio 0.84, 95% CI 0.62–1.15; P =0.28); RPM associated with 21% RR reduction in first unplanned hospitalisation for HF [hazard ratio (HR) 0.79, 95% CI 0.62–0.99; P = 0.044); Mean±SD annualised cumulative number of days in hospital 36.3±54.4 (RPM) vs 34.1±47.0 (SC) P = 0.34. Among the secondary outcomes, telemonitoring reduced the relative risk of occurrence of first unplanned hospitalisation for HF by 21% after adjustment for known predictive factors. Median time to first HF hospitalisation was also numerically delayed by 18 days in the telemonitoring group, but the difference did not reach the level of statistical significance.	No significant difference
Geller, 2019 (Germany)	RCT	Patients with CIEDs (HF)	12	333 intervention; 331 control	ICD 65 [58–70]; CRT-D 68 [62–74]; (control not reported)	ICD 85.0% male; CRT-D 77.7% male; (control group not reported)	CIED	Automatic	Passive	Not stated	All-cause	Hospitalisations for worsening HF in RPM vs. control group was 14 vs. 13 (ICD) and 30 vs. 34 (CRT-D). Number of affected patients was 10 vs. 8 (ICD: 7.0% vs. 6.1%, P = 0.81) and 17 vs. 26 (CRT-D: 8.9% vs. 13.0%; P = 0.26), the median length of hospital stay was 9.0 vs. 7.0 days (ICD: P = 0.38) and 7.0 vs. 7.5 days (CRT-D: P = 0.43), respectively.	No significant difference
Gingele, 2019 (Netherlands)	RCT	Heart failure	12	197 intervention; 185 control	71.0 ± 11.9 (Int); 71.9 ± 10.5 (control)	58% male (Int); 60% male (control)	Dedicated RPM unit	Manual	Active	"contacted with advice" "twice had personal contact with specialist"	Condition-specific	RPM group had significantly fewer HF-related hospitalisations vs. control group (IRR = 0.54, 95% CI 0.31–0.88). However, HF-related LOS was not significantly shorter in RPM group (IRR = 0.60, 95% CI 0.33–1.07).	Decreased hospitalisations, no significant diference in LOS
Hale, 2016 (USA)	RCT	Heart failure	3	11 intervention; 14 control	68.4 (11.8) (intervention); 74.4 (10.4) (control)	64% male (both)	MedSentry electronic medication device	Automatic	Active	Telephone	All-cause and condition-specific	Approximately 9% (1/11) of RPM participants were hospitalised one or more times vs. 50% (7/14) control participants (P = 0.04), a relative risk reduction in hospitalisation of approximately 82%. RPM group had significantly fewer all-cause hospitalisation days vs. controls (4 vs 34, P = 0.03) and there was a reduction in the LOS for HF-related and non-HF-related hospitalisations (NS, P = 0.24). ED presentations all cause and HF-related were reduced (NS, 6 to 3 and 3 to 1, respectively).	Decreased
Hansen, 2018 (Germany)	RCT	Patients with CIEDs (HF)	13	102 intervention; 108 control	62.5 ± 12.2 (Telemetry); 64.7 ± 9.1 (remote + phone); 65.4 ± 11.1 (visit)	16.7% female (telemetry); 13.2% female (remote + phone); 16.4% female (visit)	CIED + dedicated RPM unit	Automatic	Passive	Website	Condition-specific	HF-hospitalisation occurred at similar rates in the RPM and control groups (9.8% vs. 12.0%, P = 0.605).	No significant difference
Heidbuchel, 2015 (Various - Europe)	RCT	Patients with CIEDs (unspecified)	24	159 intervention; 144 control	62.4 ± 13.1 (ALL); 62.0 ± 13.9 (Int); 62.9 ± 12.3 (control)	80.5% male (ALL); 78% male (Int); 83.3% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	Fewer CV hospitalisations and shorter LOS in RPM patients, but NS. CV hospitalisations control vs. RPM = 0.85 (1.43) vs. 0.67 (1.18), P= 0.233; LOS (days) 8.26 (18.6) vs. 6.31 (15.5), P= 0.266.	No significant difference

Ho, 2016 (Taiwan)	RCT	COPD	6	53 intervention; 53 control	81.4 ± 7.8 (Int); 79.0 ± 9.6 (control)	81% male (Int); 72% male (control)	Website	Manual	Active	Not stated	All-cause and condition-specific	RPM associated with a significant reduction in number of all-cause re-admissions from 0.68 to 0.23 per patient (P = 0.002). RPM patients had fewer ED presentations for all causes vs. control group (0.36 vs. 0.91 per patient, P = 0.006).	Decreased
Ishani, 2016 (USA)	RCT	CKD	12	451 intervention; 150 control	75.3 ± 8.1 (Int); 74.3 ± 8.1 (control)	98.7% male (Int); 98.0% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	VC	All-cause	RPM did not reduce the risk for hospitalisation or ED presentations vs. usual care; Hospitalisations HR = 1.15; 95% CI 0.80-1.63, ED presentations HR = 0.92; 95% CI, 0.68-1.24.	No significant difference
Jenneve, 2020 (France)	Cohort	Heart failure	24	159	72.9 years (34–96)	64.3% male	Website + scale	Manual	Passive	Telephone	Condition-specific	Mean number of days hospitalised for HF per patient per year was 8.33 (6.84–10.13) in the year preceding enrollment, 2.6 (1.51–4.47) at one year of follow-up, and 2.82 at two years of follow-up (1.30–6.11) ($p < 0.01$ for both comparisons). Number of patients hospitalised for HF was 112 in the year preceding enrollment and 23 or 15 at 1 and 2 years of follow up, respectively.	Decreased
Jimenez-Marrero, 2020 (Spain)	RCT	Heart failure	6	50 intervention; 66 control	77 years	47% female	Tablet computer	Manual	Passive	Not stated	All-cause and condition-specific	There were statistically significant lower risks hospitalisations comparing telemedicine to usual care; Hospitalisation from non-cardiovascular causes was similar in the two arms- Usual care vs Telemedicine - HF hospitalisation 29 vs 10 P = 0.011 HR 0.38 (0.16–0.90); CV hospitalisation 37 vs 13 P = 0.009 HR 0.40 (0.19–0.86); Non-CV hospitalisation 12 vs 7 P= 0.796 HR 1.01 (0.35–2.88); All-cause hospitalisation 51 vs 21 P = 0.017 HR 0.52 (0.28–0.98)	Decreased
Kalter-Leibovici, 2017 (Israel)	RCT	Heart failure	30	682 intervention; 678 control	70.8 (11.6) (Int); 70.7 (11.0) (control)	69.3% male (Int); 75.7% male (control)	Dedicated RPM unit	Manual	Passive	Telephone, VC	All-cause	No significant differences in LOS (adjusted RR = 0.886; 95% CI 0.749-1.048), and hospitalisations for all causes (adjusted RR = 0.935; 95% CI 0.840-1.040).	No significant difference
Kao, 2016 (USA)	Cohort	Heart failure	36	623 intervention; 623 control	78.76 ± 9.08 (Int); 77.39 ± 8.59 (control)	56.7% male (Int); 52.3% male (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	A reduction of 22.7% in quarterly hospitalisations noted in RPM vs. matched controls (D = -0.05 hospitalisations/quarter; 95% CI -0.09 to -0.01; P = 0.012). No significant differences between RPM and matched control cohorts in all-cause LOS per quarter or all-cause ED presentations.	No significant difference in LOS or ED, decreased hospitalisations
Kenealy, 2015 (New Zealand)	RCT - except site C	Chronic conditions (unspecified)	6	98 intervention; 73 control	SITE A: 72 (62–83) (Int); 72 (60–77) (control) SITE B: 67 (64–74) (Int); 67.5 (63– 72.5) (control) SITE C: 57 (53-60) (Int); no control group	SITE A: 39% female (Int); 29% female (control); SITE B: 38% female (both); SITE C: 60% female (no control group)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause	RPM group showed no significant change in hospitalisations vs. usual care (coefficient 0.32, P = 0.15), ED presentations (coefficient -0.08, P = 0.91), or LOS (coefficient 0.51, P = 0.09).	No significant difference
Kessler, 2018 (Various - Europe (France, Germany, Italy, Spain)	RCT	COPD	12	172 intervention; 173 control	67.3 ± 8.9 (Int); 66.6 ± 9.6 (control); ALL 66.9 ± 9.3	69.4% male (Int); 69.8% male (control)	Telephone	Manual	Active	Telephone	All-cause and condition-specific	No significant difference in all-cause LOS (non-parametric analysis (p=0.161) or ANOVA comparison of the mean values adjusted for country differences (−5.3 days, 95% CI −13.7 to 3.1; P = 0.212). Difference was 7.4 ± 35.4 in RPM group and 22.6 ± 41.8 in control group, with medians (IQR) of 0 (0−203) days and 5 (0 −259) days, respectively. The total numbers of unplanned hospitalisations were similar for both groups (RPM group, n=157; control group, n=160). LOS due to acute exacerbation of COPD not significantly different.	No significant difference
Koehler, 2018 (Germany)	RCT	Heart failure	12	765 intervention; 773 control	70 (11) (Int); 70 (10) (control)	70% male (Int); 69% male (control)	Tablet + peripheral devices	Manual	Active	Telephone	Condition-specific	RPM group had shorter LOS vs. control group for unplanned hospitalisations due to worsening HF (mean 3.8 days per year, 95% CI 3.5–4.1 vs. 5.6 days per year, 5·2–6·0, respectively). The percentage of days lost for this outcome for RPM and control groups was 1.04% (95% CI 0.96–1.11) and 1.53% (1.43–1.64), respectively (ratio 0.80, 95% CI 0.67–0.95; P = 0.0070).	Decreased

Koulaouzidis, 2019 (UK)	Cohort	Heart failure	12	124 intervention; 345 control	68.1 (12.7) (Int); 67.5 (10.6) (control)	78.2 male (Int); 68.1% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause hospitalisation and condition-specific readmission	There was no difference between the two groups in all-cause hospitalisation, either in number of subjects hospitalised (P = 0.7) or in number of admissions per patient P = 0.6), No difference in number of HF-related readmissions per person between the two groups (P = 0.5), but LOS per person was higher in control group (P = 0.03).	Decreased LOS, no significant difference in hospitalisation
Kraai, 2016 (Netherlands)	RCT	Heart failure	9	94 intervention; 83 control	69 ± 12 (Int); 69 ± 11 (control);	70% male (Int); 75% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	HF-readmission 28% vs. 27% P = 0.87; All-cause readmission was 49% vs. 51% (P = 0.78).	No significant difference
Kurek, 2017 (Poland)	Cohort	Patients with CIEDs (HF)	12	287 intervention; 287 control	63 (56–69) (Int); 62 (53–70) (control)	84% male (both)	CIED + dedicated RPM unit	Automatic	Passive	Not stated	Condition-specific	Number of HF-related hospitalisations in 1-year observation was comparable (1.71 vs. 1.65 visits/per patient, P = 0.27).	No significant difference
Ladapo, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	24	2849 intervention (ICD, CRT-D and pacemaker); 2849 matched control	After matching ICD: 64 (12) (Int); 65 (12) (control); CRT-D: 69 (10) (both); pacemaker: 74 (11) (both)	After matching, ICD: 79% male (both); CRT-D: 73% male (both); Pacemaker: 55% male (both)	CIED	Automatic	Passive	Not stated	Not specified	RPM patients less likely to have ED presentations (P = 0.050) and had fewer hospital stays (P = 0.057). RPM patients did not significantly differ from control in ED presentations or hospital care. RPM patients over a 24-month period similar or less frequent utilization of emergency and hospital care, compared with those followed in the office (reductions in utilization most pronounced among ICDs).	Decreased
Lanssens, 2017 (Belgium)	Cohort	Gestational hypertensive disorders	12	48 intervention; 98 control	31.69 (4.25) (Int); 31.94 (4.77) (control)	100% female (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated ("Contacting patients at home" but did not specify how)	Not specified	Prenatal hospitalisations and hospitalisations until delivery were lower in RPM vs. control when a univariate analysis was performed - 56.25% (27/48) vs.74.49% (73/98) and 27.08% (13/48) vs. 62.24% (61/97). This was not significant in multivariate analysis.	No significant difference in multivariate analysis, decreased in univariate analysis.
Lanssens, 2018 (Belgium)	Cohort	Gestational hypertensive disorders	12	90 intervention; 320 control	30.97 (±5.61) (Int); 30.53 (±5.17) (control)	100% female (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated ("Contacting patients at home" but did not specify how)	Not specified	In both uni- and multivariate analyses, RPM group had, vs. control group, less prenatal admission (51.62% vs. 71.63%), and less prenatal admissions until the moment of the delivery (31.40% vs. 57.67%).	Decreased
Leng Chow, 2020 (Singapore)	Non-randomised controlled trial (Quasi-experimental)	Heart failure	12	150 intervention; 55 control	57.9 (Int); 63.9 (control)	60.7% male (Int); 58.2% males (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	All-cause and condition-specific	After adjusting for differences in age and years of HF diagnosis, average HF-related bed days per patient at 180 days (TM=1.2, STS=6.0 days; p<0.01) and at one year (TM=2.2, STS=6.6 days; p=0.02), remained significantly lower for TM compared with STS. Allcause bed days per patient at 180 days were also significantly lower for TM compared with STS (TM=5.0, STS=9.8 days; p=0.03); TM was associated with reduced all-cause 180-day readmission by 38% (HR 0.62 (0.38–1.00); p=0.05)	Decreased
Lew, 2018 (USA)	Non-randomised controlled trial	Peritoneal dialysis patients	Not specified	269	56 (43.6–64.3)	56.9% male	Peripheral devices	Manual	Active	VC	Not specified	Use of RPM collected weight associated with fewer hospitalisations (adjusted OR= 0.54, 95% CI 0.33–0.89) and shorter LOS (adjusted OR = 0.46, 95% CI 0.26–0.81). Use of RPM collected BP associated with longer LOS (adjusted OR = 1.95, 95% CI 1.10–3.46) and increased odds of hospitalisation (adjusted OR 1.65, 95% CI 1.02–2.65).	Decreased (when monitoring weight), increased (when monitoring BP).
López-Liria, 2020 (Spain)	Non-randomised controlled trial (Quasi-experimental)	Patients with CIEDs (unspecified)	60	21 intervention; 34 control	81 ± 7 (Int); 8 ± 6 (control)	31% women	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	Hospitalisations were 19 (90.48) in RM vs 33 (97.06) in control P = 0.323	No significant difference
Lu¨thje, 2015 (Germany)	RCT	Patients with CIEDs (unspecified)	15	73 intervention; 82 control	66.0 (± 12.0) (Int); 65.9 (± 12.1) (control)	80.5% male (Int); 74.2% male (control)	CIED	Automatic	Passive	Telephone	Condition-specific	The mean number of ED presentations was not significantly different between the two groups (RPM group 0.10 + 0.25 vs. control group 0.10 + 0.23; P = 0.7295). 20 RPM patients and 22 control patients were hospitalised for worsened HF (no significance test stated).	No significant difference

Lyth, 2019 (Sweden)	Cohort	HF, COPD	12	94	HF: 84 (65–100) COPD: 74 (65–86)	HF: 50% female COPD: 61.1% female	Digital pen and Health Diary System	Manual	Active	SMS	Condition-specific	Hospitalisations was 0.94 for HF and 1.16 for COPD. This was significantly lower than expected, with 67% in the HF group (P<0.001) and 61% in the COPD group (P = 0.003). Mean values for inpatient care and emergency care in HF and COPD significantly lower in observed vs. expected (P<0.001).	Decreased
Martin-Lesende, 2017 (Spain)	Cohort	HF, COPD or other chronic lung disease	12	28	78.9 (7.5)	45.3% male	Smartphone	Manual	Passive	SMS	All-cause and condition-specific	Significant reduction in hospitalisations, from 2.6 admissions/patient in the previous year (SD: 1.6) to 1.1 (SD: 1.5) during the one year RPM follow-up (P<0.001), and ED presentations, from 4.2 (SD: 2.6) to 2.1 (SD: 2.6) (P<0.001) was observed. The LOS was reduced non-significantly from 11.4 to 7.9 days.	Decreased hospitalisations and ED, no significant difference in LOS
McDowell, 2015 (UK)	RCT	COPD	6	48 intervention; 52 control	69.8 (7.1) (Int); 70.2 (7.4) (control)	58.2% female (Int); 54.5% female (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated - ("Contacted patient" but did not specify how)	Not specified	At 6 months there was a higher number of ED presentations, hospitalisations and longer LOS in control group vs. RPM group, but differences were NS (P = 0.40, P = 0.42, P = 0.59 respectively).	No significant difference
McElroy, 2016 (USA)	Cohort	Patients post surgery (cardiac)	1	27 intervention; 416 control	62.9 (9.8) (intervention); 65.9 (14.1) (control)	85.2% male (intervention); 65.9% male (control)	Tablet + peripheral devices	Manual	Active	Telephone, VC	Not specified	Readmission rate for the RPM and control groups were similar (7.4% vs. 9.9%, P = 0.65). LOS 9.1 ± 9.0 vs. RPM 8.7 ± 3.6 P = 0.65.	No significant difference
Milan Manani, 2020 (Italy)	Case-control	Peritoneal dialysis patients	6	35 intervention; 38 control	62.8 (44.7–77.1) (Int); 57.9 (50.0–73.1) (control)	77% male (intervention); 71% male (control)	NS	Both	NS	Not stated	All-cause and condition-specific	Decreased disease-specific hospitalizations (RPM 18.2% versus control 77.8%) (p = 0.022); 4 reasons for ED visits and significantly decreased two: Overhydration, mean ± SD RPM 0.17 ± 0.45bs control 0.66 ± 1.36 P = 0.0421; Exit site infections, mean ± SD RPM 0.17 ± 0.56 vs 0.42 ± 0.85 P = 0.0451.	Decreased
Mirón Rubio, 2018 (Spain)	Cohort	COPD	6	26	78 (7.9)	93% male	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone, In-person	Not specified	The number of ED presentations decreased by 38%, from 53 visits during control period (in 26 (92.9%) patients; mean 1.89 visits/patient; range 0–6) to 33 visits during RPM period (in 15 (53.6%) patients; mean 1.18 visits/patient; range 0–6, p = 0.03). Fewer hospitalisations or ED presentations during RPM period: only 15 patients (53.6%) vs. 26 (92.8%) patients during control period (RR = 0.58; CI 95% 0.40 – 0.83, P =0.002).	Decreased
Mizukawa, 2019 (Japan)	RCT	Heart failure	24	15 (Int); 15 (control)	70.5 ± 13.3 (Int); 74.5 ± 12.1 (control)	50% male (intervention); 52.6% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause and condition-specific	Rates of readmission for HF were significantly different (P = 0.048), with significant improvement in the CM group, as compared with the UC group (P = 0.020). The hazard ratio for HF readmissions in the CM group versus the UC group was 0.29 (95% CI, 0.09 to 0.92; P = 0.035)	Decreased
Nancarrow, 2016 (Australia)	Cohort	Geriatric	12	200	74.8 ± (8.2)	41.5% male	Tablet + peripheral devices	Manual	Active	VC	Not specified	Self-reported health service use showed decline in ED presentations (X^2= 14.950, n = 122; 6 df, P = 0.021); hospitalisation (non-local) (x^2 61.44, n = 118, 12 df, P< 0.001). However, there was no significant difference in hospitalisation in the local hospital (c^2 21.190, n = 122; 16 df, P = 0.171).	Decreased ED, no significant difference local hospitalisations
Nouryan, 2019 (USA)	RCT	Heart failure	6	42 intervention; 47 control	81.4 (Int); 84.9 (control)	32% male	Dedicated RPM unit + peripheral devices	Manual	Active	VC, Feedback reports to patient as well	All-cause and condition-specific	38% of RPM patients had ≥1 ED presentation vs. 60% of control (P = 0.04), while 48% of RPM had ≥1 hospitalisation vs. 55% of control (P = 0.47). LOS (days) was 4.0 for RPM vs. 7.4 for control (P = 0.39).	Decreased ED, hospitalisation and LOS not significantly different
Nunes-Ferreira, 2020 (Portugal)	Quasi-experimental	Heart failure	12	25 intervention; 50 control	65.4 ± 9.7 (Int); 64.58 ± 13.73 (control)	32% female (Int); 38% female (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Not stated	All-cause and condition-specific	RPM significantly reduced HF-related hospitalisation rate (12% vs. 36%, HR 0.29; 95% CI 0.10–0.89; P < 0.05) and all-cause hospitalisations (HR 0.29; 95% CI 0.11–0.75; P < 0.001); Patients in the TM group lost an average of 5.6 days per year compared with 48.8 days in the UC group.	Decreased
Olivari, 2018 (Italy)	RCT	Heart failure	12	229 intervention; 110 control	79.6 ± 6.8 (Int); 80.9 ± 7.3 (control)	61.1% male (Int); 65.4% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Not stated	All-cause	In the RPM and control group respectively, mean LOS of 13.1 ± 16.3 and 16.5 ± 32.0 (P = 0.21) days. Hospitalisations for HF occurred in 161 and 93, with a mean LOS of 13.5 ± 14.2 and 19.0 ± 39.3 (P = 0.20) days, in the RPM and control group, respectively.	No significant difference
Ong, 2016 (USA)	RCT	Heart failure	6	715 intervention; 722 control	73 (62-84) (Int); 74 (63-82) (control)	46.6% (42.9-50.2) female (Int); 47.1% female (42.8-51.4) (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	All-cause	The RPM and control groups did not differ significantly in readmissions for any cause 180 days after discharge, which occurred in 50.8% (363 of 715) and 49.2% (355 of 722) of patients, respectively (adjusted HR = 1.03; 95% CI 0.88-1.20; P = 0.74).	No significant difference
Orozco-Beltran, 2017 (Spain)	Quasi-experimental	Chronic conditions (unspecified)	12	521	70.4 (10.3)	38.9% female	Tablet	Manual	Passive	Telephone, VC	All-cause and condition-specific	Decrease in ED presentations (98, 18.8% vs. 67, 12.8%; P<.001). Fewer hospitalisations due to an emergency (105, 20.2% vs. 71, 13.6%; P<.001) or disease exacerbation (55, 10.5% vs. 42, 8.1%; P<.001).	Decreased

Pedone, 2015 (Italy)	RCT	Heart failure	6	50 intervention; 46 control	79.9 ± 6.8 (Int); 79.7 ± 7.8 (control)	46.8% male (Int); 30.2% male (control)	Smartphone + peripheral devices	Manual	Active	Telephone	All-cause	Hospitalisations during the 6 months of follow-up: 20 in control group (incidence rate 129/100 person-years, 95% CI = 84–200) and 8 (incidence rate 39/100 person-years, 95% CI = 20–77) in RPM group (IRR = 0.30, 95% CI 0.12–0.67).	Decreased
Pekmezaris, 2019 (USA)	RCT	Heart failure	3	46 intervention; 58 control	58.4 (15.2, 19–93) (Int); 61.1 (15.0, 26–90) (control)	43% female (Int); 40% female (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone, VC	All-cause and condition-specific	Groups did not differ regarding binary ED presentations (RR = 1.37, CI 0.83–2.27), hospitalization (RR = 0.92, CI 0.57–1.48), or length of stay in days (RPM = 0.54 vs. control =0.91). Number of all-cause hospitalisations was significantly lower for control (RPM= 0.78 vs. control = 0.55; P = 0.03).	No significant difference in binary ED, hospitalisation, or LOS, increased for all-cause hospitalisation
Persson, 2019 (Sweden)	Cohort	HF, COPD	12	53	HF - 83±7 (65–100); COPD - 75±6 (65–86)	54.2% female	Digital pen and Health Diary System	Manual	Passive	Not stated	All-cause	Compared to adjusted hospitalization rates prior inclusion, the intervention significantly reduced hospitalization rates for both groups	Decreased
Piccini, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	19	34,259 intervention; 58,307 control	69.7 ± 12.7 (Int); 72.6 ± 13.1 (control)	66.1% male (Int); 60.9% male (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM had lower adjusted risk of all-cause hospitalisation (adjusted HR = 0.82; 95% CI 0.80–0.84; P = 0.001) and shorter mean LOS (5.3 days vs. 8.1 days, P < 0.001).	Decreased
Ricci, 2017 (Italy)	Quasi-experimental	Patients with CIEDs (unspecified)	12	102 intervention; 107 control	69.69 ± 10.17 (Int); 68.89 ± 11.46 (control)	84.31% male (Int); 85.98% (control)	CIED + transmitter	Automatic	Passive	Dedicated RM unit message	Condition-specific	More CV-related hospitalisations in control vs. RPM patients (SC: 22 (24.72%) vs. RPM: 7 (8.14%); P = 0.0032); more ED presentations (control: 5 (5.62%) vs. RPM: 0 (0.00%); P = .059); Regarding CV hospitalisations, there was no statistically significant difference in LOS between patients with RPM and control patients (6.6 ± 4.7 days [44 hospitalizations] vs. 6.4 ± 4.8 days [14 hospitalizations], P = 0.8990).	Decreased ED and hospitalisations, no significant difference in LOS
Riley, 2015 (USA)	Cohort	Heart failure	6	45 intervention; 45 control	Of those matched 65.9 (14.7)	Of those matched 48.9% female	Smartphone + peripheral devices	Manual	Active	Not stated	Not specified	Matched cohort saw similar decrease pre/post as RPM saw pre/post. For comparing directly enrolled vs. matched at 30 days post - 0.47 (1.10) vs. 0.56 (0.87); 60 days 1.24 (3.24) vs. 0.87 (1.44); 182 days 1.87 (4.54) vs. 1.22 (1.71). For enrolled vs. matched, at 30 days, time F (1,88) = 43.87, p < 0.0001, time · group = 0.63, p = 0.429; at 90 days, time F (1,88) = 50.87, p < 0.0001, time · group = 0.12, p = 0.727; and at 182 days, time F (1,88) = 45.36, p < 0.0001, time · group = 1.00, p = 0.320.	No significant difference
Ringbæk, 2015 (Denmark)	RCT	COPD	6	141 intervention; 140 control	69.8 (9.0) (Int); 69.4 (10.1) (control)	61% female (Int); 45% female (control)	Tablet + peripheral devices	Manual	Active	VC	Condition-specific	No significant difference found in hospital admissions for COPD between the groups (P = 0.74).	No significant difference
Rosner, 2018 (USA)	Cohort	Patients post surgery (orthopaedic)	3	186 intervention; 372 control;	57.00 (7.32)	50% female	Website	Manual	Active	E-mail	Not specified	90 day hospitalisation rates in baseline and RPM groups were 3.0% (11 of 372) and 1.6% (3 of 186), respectively (RR = 0.545; CI 0.154 - 1.931, P = 0.40).	No significant difference
Sanabria, 2019 (Colombia)	Cohort	Peritoneal dialysis patients	12	360	57±17	44% female	Dedicated RPM unit	Manual	Both	Not stated	Not specified	RPM decreased hospitalization rate (0.36 fewer hospitalizations per patient-year; IRR 0.61 [95% CI 0.39 – 0.95]; p = 0.029) and hospitalization days (6.57 fewer days per patient-year; IRR 0.46 [95% CI 0.23 – 0.92]; p = 0.028).	Decreased
Sardu, 2016 (USA)	RCT	Patients with CIEDs (HF)	12	89 intervention; 94 control	71.8 ± 8.5 (Int); 72.6 ± 5.7 (control)	71.9 male (Int); 79.8% male (control)	CIED	Automatic	Active	Telephone, In-person	Condition-specific	There was a significant difference in hospitalisations (15.7 vs. 28.7, P = 0.02) comparing RPM patients to control group. At multivariate analysis, RPM was the only factor predicting HF hospitalisation (HR = 0.6, 95% CI 0.42–0.79, P = 0.002).	Decreased
Shany, 2017 (Australia)	RCT	COPD	12	11 intervention; 18 control	72.1 ± 7.5 (Int); 74.2 ± 9.0 (control)	48% male (Int); 43% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Condition-specific	No statistically significant differences were demonstrated for the rate of ED presentations and hospitalisations. However, during the study, being in RPM group was associated with 20% relative reduction in the risk of admission and 14% relative reduction in the risk of ED presentation. Analysed as LOS per admission, there was no significant difference between the control and RPM patients.	No significant difference, though some relative reduction in risk
Sink, 2018 (USA)	RCT - except 17 non-randomised participants	COPD	8	83 intervention; 85 control	59.89 ± 1.09 (Int); 61.94 ± 1.07 (control)	34.9% male (Int); 37.6% male (control)	Smartphone	Manual	Passive	Not stated	Condition-specific	There were significantly fewer COPD-related hospitalisations in RPM group vs. control with 6 and 16, respectively. The absolute RR was 11.6% and the relative RR was 61.7%.	Decreased
Soriano, 2018 (Spain)	RCT	COPD	12	87 intervention; 82 control	71.5 ± 8.0 (Int); 71.3 ± 8.9 (control)	78.3% male (Int); 82.5% male (control)	Telephone	Manual	Passive	SMS	Condition-specific	Shorter mean LOS in RPM group (18.9 ± 16.1 days) compared to the control group (22.4 ± 19.5 days, P = 0.308). There were no statistically significant differences in primary efficacy analysis of the proportion of participants who had a severe exacerbation leading to a hospital admission or ED presentation over the 12-month period (60% in RPM vs. 53.5% in control, P = 0.321).	No significant difference

Srivastava, 2019 (USA)	Cohort	Heart failure	12	197 intervention; 870 control	73.4 (11.14) (Int); 75.4 (11.0) (control)	98.0% male (Int); 97.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	A significantly lower total admissions (1.1 vs. 1.6 admissions) and LOS (5.7 vs. 11.3 days) were seen in RPM group compared to the prior year (1.6 vs. 1.7, P<0.05; and 9.5 vs. 14 days, P<0.01, respectively). The RPM group also had a significantly lower LOS vs. control group (9.0 vs. 14.9, P<0.01). However, there was no significant difference in hospitalisations between the RPM group and control group (1.4 vs. 2.0, P<0.07). The number of ED presentations was not significantly different.	Decreased if looking pre-post, no significant difference compared to controls
Stamenova, 2020 (Canada)	RCT	COPD	6	41 intervention; 40 control	71.98 (9.52) (Int); 72.78 (9.16) (control)	44% female (Int); 48% female (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition specific	No significant difference in number of ED visits and hospitalizations during the 6 months preceding enrollment and during their participation in the trial. For COPD-related hospital admissions, there was a decrease but not a statistically significant effect across the 3 groups (P=0.07). No effect for COPD-related ED visits.	No significant difference
Tajstra, 2020 (Poland)	RCT	Patients with CIEDs (HF)	12	299 intervention; 301 control	64.0 (13.0) (Int); 64.0 (12.0) (control)	81.6% male (Int); 80.7% male (control)	CIED + dedicated RPM unit	Automatic	Both	Not stated	Condition-specific	Hospitalization rate due to cardiovascular reasons was higher in control as compared to RPM (45.5% vs 37.1%, P = 0.045).	Decreased
Ten Eyck, 2019 (USA)	Cohort	Heart failure	12	Different levels of "engaged" interventions 8907; 8907 control	73.0 (9.92) (Int); 73.68 (10.6) (control)	46.3% male (Int - engaged); 47.5% male (control - non-engaged)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Engaged members who used their Bluetooth-enabled scales an average of 25 or more days per month demonstrated significantly lower post-index acute IP medical service utilisation vs. control group members (P<0.0001). Conversely, engaged members who used their scales ≤ 9 days per month or 9.1 to 18 days per month had significantly higher post-index acute IP medical service utilisation vs. control group (P< 0.0001 and P = 0.008, respectively). Engaged members had a significantly shorter average LOS vs. non-engaged members (4.14 vs. 4.66 days; P< 0.0001).	Decreased
Thomason, 2015 (USA)	Cohort	Heart failure	3	80 intervention; 1276 control	83.75 (SD 8.61) (Int); 81.97 (SD 10.55) (control)	60% female (Int); 60.2% female (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	Control group had a 21% all-cause hospital readmission rate vs. RPM group who had a 10% all-cause readmission rate.	Decreased
Trucco, 2019 (Italy)	Cohort	Home-ventilated neuromuscular patients	14	48 intervention; 48 control	16.4 (8.9–22.1) (Int); 15 (9.2–21.5) (control)	62.5% male (Int); 75.0% male (control)	Dedicated RPM unit + peripheral devices	Both	Passive	Telephone, VC	Condition-specific	Hospitalisations were significantly reduced post-RPM patients when compared to pre-RPM (11 vs. 24, P = 0.04) and to controls (11 vs. 21, P = 0.03). Median LOS was significantly lower in RPM patients vs. controls (6 vs. 7 days, P = 0.03). ED presentations were significantly reduced during the RPM trial (from 12 to 2, P<0.05) while hospital admissions were not significantly lower during RPM compared with pre-RPM (from 12 to 9 P>0.05).	Decreased hospitalisations, LOS, ED
Udsen, 2017 (Denmark)	Cluster RCT	COPD	12	578 intervention; 647 control	69.55 (9.36) (Int); 70.33 (9.11) (control)	48.27% male (Int); 43.74% male (control)	Tablet + peripheral devices	Manual	Active	Not stated	Condition-specific	Mean (SE) = Hospital admissions: RPM 2756.1 (463.8) vs. usual care 2753.1 (458.9); ED presentations 343.4 (24.8) vs. usual care 278.3 (21.5); Resource use is consistently higher in the RPM group.	Increased
van den Heuvel, 2020 (Netherlands)	Case-control	Gestational hypertensive disorders	9	103 intervention; 133 control	33.7 (4.6) (Int); 33.1 (4.7) (control)	100% female (maternal study)	Dedicated RPM unit + peripheral devices	Manual	Both	Not stated	Condition-specific	Observational admissions for hypertension or diagnosis/exclusion of suspected preeclampsia were significantly lower in RPM compared to the control group (2.9% vs 13.5% of participants, p = 0.004).	Decreased
Vianello, 2016 (Italy)	RCT	COPD	12	181 intervention; 81 control	75.96 (6.54) (Int); 76.48 (6.16) (control)	72.2% male (Int); 73.1% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone (only home visit for event management)	All-cause and condition-specific	The hospitalization rate for COPD and/or for any cause was not significantly different in the two groups (IRR = 0.89, 95% CI 0.79–1.04, P = 0.16 and IRR = 0.91, 95% CI 0.75 – 1.04); p = 0.16, respectively). The readmission rate for COPD and/or any cause was, however, significantly lower in the RPM group vs. control (IRR = 0.43, 95% CI 0.19–0.98, P = 0.01 and 0.46, 95% CI 0.24–0.89, P =0.01, respectively). LOS was not significantly different in the two groups.	No significant difference
Wagenaar, 2019 (Netherlands)	RCT	Heart failure	12	150 intervention; 150 control	66.6 ± 11.0 (Int); 66.9 ± 11.6 (control)	75.3% male (Int); 72.7% male (control)	Website	Manual	Passive	Telephone, Website	All-cause and condition-specific	No difference in hospitalisations (RPM vs. UC, 57 vs. 66, HR = 0.85, 95% CI 0.59–1.21).	No significant difference
Walker, 2018 (UK, Estonia, Sweden, Spain, Slovenia)	RCT	COPD	9	154 intervention; 158 control	71.0 (66.0, 75.8) (Int); 71.0 (65.3, 76.0) (control)	65.6% male (Int); 66.5% male (control)	Tablet + peripheral devices	Manual	Passive	Telephone	Not specified	The average LOS for all cause hospitalisations was 4.0 (IQR:1.0 - 9.0) days for control group and 1.0 (IQR:1.0 - 6.7) day for RPM group (P = 0.045). Compared to control, RPM patients who were hospitalised during the trial (n=41 and 45, respectively) were less than half as likely to be re-hospitalised (IRR = 0.46, P = 0.017). There was no difference between groups in the rate of hospitalisation (0.79 vs. 0.99, P = 0.276).	Decreased LOS, no significant difference in hospitalisation

Ware, 2020 (Canada)	Cohort	Heart failure	6	156	58.3 (15.5)	77.8% male	Smartphone + peripheral devices	Manual	Passive	Not stated	All-cause and condition-specific	HF-related hospitalizations decreased from 0.46 (0-4, 0.71) to 0.23 (0-3, 0.51); IRR 0.50 (P<.001). All-cause hospitalizations decreased from 0.64 (0-7, 0.89) to 0.49 (0-6, 0.97); IRR 0.76 (P=.02). LOS & ED visits (HF related and all cause) no significant difference between baseline and 6 months.	Decreased hospitalisations but no change LOS and ED.
White-Williams, 2015 (USA)	Cohort	Heart failure	3	235 intervention; 91 control	77 (Int); 71 (control)	47.7% male (Int); 52.7% male (control)	Remote monitoring system/device (not specified)	Manual	Active	Telephone	Not specified	The results of the tests indicated that there was no statistical significant difference in ED presentations and hospital readmissions between usual care and RPM group (Pearson chi-squared = 0.518 and 0.086, respectively, P > .05).	No significant difference
Williams, 2016 (USA)	Case control	Heart failure	2	105 intervention; 210 control	NR	43.8% male (Int); 46.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Condition-specific	No significant associations between RPM and hospital readmissions, $\chi 2$ = (1, n = 210, p-value = 0.71, phi = 0.71)	No significant difference
Zakeri, 2020 (UK)	Cohort	Patients with CIEDs (HF and AF)	34	1561; No AF - 616 interventoin; 595 control; Paroxysmal - 57 Intervention, 35 control; PP AF -134 intervential, 124 contorl	NR	NR	CIED	Automatic	NS	Not stated	All-cause and condition-specific	In patients with persistent/permanent AF, RM increased risk of recurrent cardiovascular (HR 1.40, 95% CI 1.06–1.85, P = 0.018] and HF-related (HR 2.05, 95% CI 1.14–3.69, P = 0.016) hospitalisations; For patients with paroxysmal AF and no AF, there was no difference in the risk of CV or HF-related hospitalisation (as a first or recurrent event) with RPM vs. usual care; When the dataset was truncated after the fifth hospitalisation (n = 103 CV hospitalisations excluded), the positive association between RPM and HF-related hospitalisations for patients with persistent/permanent AF remained statistically significant (HR 1.84, 95% CI 1.07–3.17, P = 0.027), while the association with CV hospitalisations was borderline significant (HR 1.32, 95% CI 1.00–1.75, P = 0.054).	Increased

CI = confidence interval; CIED: cardiovascular implantable electronic device; COPD = chronic obstructive pulmonary disease; CRT-D = cardiac resyncronisation therapy defibrillator; CV = cardiovascular; df= degrees of freedom; ED = emergency department; HF = heart failure; HR = hazard ratio; IBD=inflammatory bowel disease; ICD= implantable cardioverter defibrillator; Int= Intervention/RPM group; IQR = inter-quartile range; IRR = incidence rate ratio; LOS = length of stay; NS = not significant; OR = odds ratio; RCT = randomised controlled trial; RPM = remote patient monitoring; RR = risk ratio or risk reduction; SD = standard deviation

Supplementary Table 2. Participant vitals monitored by RPM device in each study

First author, Year	Patient Group or Disease	Comorbidities mentioned	BP	HR	SpO2	HbA1c	Weight	Temp	ECG	FEV1	Patient or informant questionnaires (e.g. symptoms)	Other
Celler, 2018	Chronic conditions (unspecified)	Yes	X	X	X			X	X	X		
Kenealy, 2015	Chronic conditions (unspecified)	Yes	X		X	X	X					
Orozco-Beltran, 2017	Chronic conditions (unspecified)	Yes	X		X	X	X			X		
Chatwin, 2016	Chronic lung disease (COPD and chronic respiratory failure)	Yes	X	X	X		X				X	
Ishani, 2016	CKD	Yes	X	X	X	X	X					
Ho, 2016	COPD	NS	X		X		X	X			X	Other "Vital signs" (NS)
Sink, 2018	COPD	NS									X	Breathing rating (better, worse, or
Achelrod, 2017	COPD	Yes			X					X	X	
Alshabani, 2019	COPD	Yes										Adherence - inhaler
Clarke, 2018	COPD	Yes	X		X		X	X			X	
Esteban, 2016	COPD	Yes		X	X			X			X	Activity + respiratory rate
Kessler, 2018	COPD	Yes										"Health status information"
McDowell, 2015	COPD	Yes	X	X	X						X	
Mirón Rubio, 2018	COPD	Yes	X	X	X							
Ringbæk, 2015	COPD	Yes			X		X			X	X	
Shany, 2017	COPD	Yes	X	X	X	X	X	X	X	X	X	
Soriano, 2018	COPD	Yes	X		X					X		oxygen therapy
Stamenova, 2020	COPD	Yes	X		X		X	X			X	
Udsen, 2017	COPD	Yes	X	X	X		X					
Vianello, 2016	COPD	Yes		X	X							
Walker, 2018	COPD	Yes	X	X	X			X				Respitartory measures (forced oscillation technique)
Bohingamu Mudiyanselage, 2019	COPD or Diabetes	Yes	X	X	X	X						
Nancarrow, 2016	Geriatric	Yes	X		X	X	X	X				Other "Vital signs" (NS)
Lanssens, 2017	Gestational hypertensive disorders	Yes	X				X					Activity
Lanssens, 2018	Gestational hypertensive disorders	Yes	X				X					Activity
van den Heuvel, 2020	Gestational hypertensive disorders	Yes	X								X	
Bingler, 2018	Heart disease - infants	NS			X		X					
Gingele, 2019	Heart failure	NS									X	
Hale, 2016	Heart failure	NS										Adherence - medication
Koehler, 2018	Heart failure	NS	X	X	X		X		X		X	
Nouryan, 2019	Heart failure	NS	X	X	X		X					
Thomason, 2015	Heart failure	NS	X	X	X		X				X	
White-Williams, 2015	Heart failure	NS									X	"Vital signs" (NS)
Agboola, 2015	Heart failure	Yes	X	X	X		X				X	
Amir, 2017	Heart failure	Yes										Lung fluid content
Comin-Colet, 2016	Heart failure	Yes	X	X			X				X	
Galinier, 2020	Heart failure	Yes	X	X	X		X		X		X	
Jenneve, 2020	Heart failure	NS	X	X			X					

Jimenez-Marrero, 2020	Heart failure	Yes					X					"heart failure signs & symptoms" not specified
Kalter-Leibovici, 2017	Heart failure	Yes	X	X			X					
Kao, 2016	Heart failure	Yes									X	"Vitals" (NS)
Koulaouzidis, 2019	Heart failure	Yes					X					
Kraai, 2016	Heart failure	Yes					X				X	
Leng Chow, 2020	Heart failure	Yes	X	X			X					
Mizukawa, 2019	Heart failure	Yes	X	X			X					
Nunes-Ferreira, 2020	Heart failure	Yes	X	X	X		X	X	X			Steps, body water content
Olivari, 2018	Heart failure	Yes	X	X	X		X		X			
Ong, 2016	Heart failure	Yes	X	X			X				X	
Pedone, 2015	Heart failure	Yes	X	X	X							
Pekmezaris, 2019	Heart failure	Yes	X	X	X		X					
Riley, 2015	Heart failure	Yes	X	X	X		X					
Srivastava, 2019	Heart failure	Yes	X	X	X		X					
Ten Eyck, 2019	Heart failure	Yes					X				X	
Wagenaar, 2019	Heart failure	Yes	X	X			X					
Ware, 2020	Heart failure	NS	X	X			X					
Williams, 2016	Heart failure	Yes	X	X	X		X					
Davis, 2015	HF, COPD	Yes		X	X		X					
Lyth, 2019	HF, COPD	Yes									X	Intake - medication
Persson, 2019	HF, COPD	Yes	X		X		X	X		X	X	
Martin-Lesende, 2017	HF, COPD or other chronic lung disease	Yes	X	X	X		X				X	Respiratory rate
Trucco, 2019	Home-ventilated neuromuscular patients	Yes		X	X							IPAP, EPAP, breathing patterns
Cross, 2019	Inflammatory bowel disease	NS									X	
De Luca, 2016	Nursing home patients; Mental health	Yes	X		X				X			
McElroy, 2016	Patients post surgery (cardiac)	Yes	X	X	X		X				X	
Rosner, 2018	Patients post surgery (orthopaedic)										X	
De Simone, 2019	Patients with CIEDs (AF)	Yes		X								Heart rhythm, device functioning, arrhythmic episodes
Böhm, 2016	Patients with CIEDs (HF)	Yes										Intrathoracic fluid
Boriani, 2017	Patients with CIEDs (HF)	Yes										Lung fluid content and atrial tachyarrhythmia,
Capucci, 2017	Patients with CIEDs (HF)	Yes		X								Heart rhythm, device functioning
Geller, 2019	Patients with CIEDs (HF)	NS		X					X			Heart rhythm, device functioning
Hansen, 2018	Patients with CIEDs (HF)	NS		X					X			Heart rhythm, device functioning
Kurek, 2017	Patients with CIEDs (HF)	Yes		X								ICD data - NS
Sardu, 2016	Patients with CIEDs (HF)	Yes		X								ICD data - NS
Tajstra, 2020	Patients with CIEDs (HF)	Yes	X	X					X			Heart rhythm, device functioning
Zakeri, 2020	Patients with CIEDs (HF and AF)	Yes	X	X					X			Heart rhythm, device functioning
Heidbuchel, 2015	Patients with CIEDs (unspecified)	NS		X					X			Heart rhythm, device functioning

Ricci, 2017	Patients with CIEDs (unspecified)	NS											ICD data - NS
Akar, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Amara, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning, atrial tachyarrhythmia
Buchta, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Bulava, 2016	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
D'Ancona, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
De Simone, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Ladapo, 2016	Patients with CIEDs (unspecified)	Yes		X									Cardiac monitoring - (NS)
López-Liria, 2020	Patients with CIEDs (unspecified)	NS	X	X						X			Heart rhythm, device functioning
Lu¨thje, 2015	Patients with CIEDs (unspecified)	Yes											Fluid index
Piccini, 2016	Patients with CIEDs (unspecified)	Yes											ICD data - NS (e.g. Heart rhythm, device functioning, arrhythmias)
Lew, 2018	Peritoneal dialysis patients	Yes	X				X						
Milan Manani, 2020	Peritoneal dialysis patients	Yes	X				X						
Sanabria, 2019	Peritoneal dialysis patients	Yes	X				X						Ultrafiltration profile, initial drainage
Flaherty, 2017	Schizophrenia	NS										X	
TOTALS			**49**	**52**	**39**	**6**	**44**	**10**	**13**	**7**	**29**		

AF = atrial fibrillation; BP = blood pressure; CIED: cardiovascular implantable electronic device; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; ECG = electrocardiogram; EPAP = expiratory positive airway pressure; FEV1 = forced expiratory volume-one second; HbA1c = glycated haemoglobin; HF = heart failure; HR = heart rate; ICD= implantable cardioverter defibrillator; IPAP = inspiratory positive airway pressure; NS = not stated; SpO2= oxygen saturation

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMAreporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
Title			
	#1	Identify the report as a systematic review, meta-analysis, or both.	1
Abstract			
Structured	#2	Provide a structured summary including, as applicable:	2

summary		background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Introduction			
Rationale	#3	Describe the rationale for the review in the context of what is already known.	3
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
Methods			
Protocol and registration	#5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	3
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	4
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last	3

		searched.	
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	4
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	5
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	5-6
Planned methods of	#14	Describe the methods of handling data and combining results of studies, if done, including measures of	5-6

analysis		consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	n/a but mention this bias on p.10
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
Results			
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	Supplementary Table 1
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	8
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	Supplementary Table 1
Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	6-8

Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	n/a but mention this bias on p.10
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	6-11
Discussion			
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers	8-10
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	10
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	10
Funding			
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	11

BMJ Open

Does remote patient monitoring reduce acute care use? A systematic review

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2020-040232.R2
Article Type:	Original research
Date Submitted by the Author:	01-Feb-2021
Complete List of Authors:	Taylor, Monica ; University of Queensland, Centre for Online Health, Centre for Health Services Research Thomas, Emma; University of Queensland Centre for Online Health, Centre for Online Health, Centre for Health Services Research Snoswell, Centaine; University of Queensland Centre for Online Health, Centre for Health Services Research Smith, Anthony; The University of Queensland, Centre for Online Health, Centre for Health Services Research Caffery, Liam; The University of Queensland, Centre for Online Health, Centre for Health Services Research
Primary Subject Heading:	Health services research
Secondary Subject Heading:	Patient-centred medicine
Keywords:	HEALTH SERVICES ADMINISTRATION & MANAGEMENT, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Telemedicine < BIOTECHNOLOGY & BIOINFORMATICS

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Does remote patient monitoring reduce acute care use? A systematic review

Ms Monica Taylor[1] – ORCiD 0000-0001-5333-2955
Dr Emma E Thomas[1] – ORCiD 0000-0001-8415-0521
Dr Centaine L Snoswell[1] – ORCiD 0000-0002-4298-9369
Professor Anthony C Smith[1] – ORCiD 0000-0002-7756-5136
Associate Professor Liam J Caffery[1] – ORCiD 0000-0003-1899-7534

1. Centre for Online Health, Centre for Health Services Research, The University of Queensland, Brisbane, Australia.

Corresponding author:
Associate Professor Liam Caffery
Ground Floor, Building 33, Princess Alexandra Hospital
Woolloongabba QLD 4102
Australia
l.caffery@uq.edu.au

Word Count: 3982

Abstract

Objective: Chronic diseases are associated with increased unplanned acute hospital use. Remote patient monitoring (RPM) can detect disease exacerbations and facilitate proactive management, possibly reducing expensive acute hospital usage. Current evidence examining RPM and acute care use mainly involves heart failure and omits automated invasive monitoring. This study aimed to determine if RPM reduces acute hospital use.

Methods: A systematic literature review of Pubmed, EMBASE and CINAHL electronic databases was undertaken in July 2019 and updated in October 2020 for studies published from January 2015 to October 2020 reporting RPM and effect on hospitalisations, length of stay, or emergency department presentations. All populations and disease conditions were included. Two independent reviewers screened articles. Quality analysis was performed using the Joanna Briggs Institute checklist. Findings were stratified by outcome variable. Subgroup analysis was undertaken on disease condition and RPM technology.

Results: From 2,050 identified records, 91 studies were included. Studies were medium to high quality. RPM for all disease conditions was reported to reduce admissions, length of stay, and emergency department presentations in 49% (n=44/90), 49% (n=23/47), and 41% (n=13/32) of studies reporting each measure, respectively. Remaining studies largely reported no change. Four studies reported RPM increased acute care use. RPM of chronic obstructive pulmonary disease (COPD) was more effective at reducing emergency presentation than RPM of other disease conditions. Similarly, invasive monitoring of cardiovascular disease was more effective at reducing hospital admissions versus other disease conditions and non-invasive monitoring.

Conclusion: RPM can reduce acute care use for cardiovascular disease and COPD patients. However, effectiveness varies within and between populations. RPM's effect on other conditions is inconclusive due to limited studies. Further analysis is required to understand underlying mechanisms causing variation in RPM interventions. These findings should be considered alongside other benefits of RPM, including increased quality of life for patients.

Generic keywords: telehealth; telemedicine; telecare; remote monitoring; telemonitoring; in-home monitoring; hospitalization; length of stay

ScholarOne keywords: Telemedicine, Health Services Administration & Management, International health services

Strengths and limitations

- This systematic review was not limited by disease condition and gives an overall picture on the effect of remote patient monitoring on acute care hospital use.
- We have included sub-analyses and new evidence, particularly for COPD patients and monitoring using implanted devices.
- Due to heterogeneity of included studies we were unable to perform a meta-analysis.

Introduction

Many people find it challenging to self-manage complex and co-morbid conditions and identify warning signs of exacerbation. Healthcare providers often only become aware of a decline in an

individual's condition once symptoms have become severe enough to require escalation to acute care. This scenario may be avoided by using remote patient monitoring (RPM).

RPM or telemonitoring refers to the recording and transmission of patient biometrics, vital signs, and/or disease-related data to a healthcare provider using information and communications technology.[1] RPM data are disease-specific and commonly include measurements like blood pressure, weight, heart rate, respiration rate, pulse oximetry, spirometry, temperature, blood glucose levels or specific symptoms.[2] Data can be collected automatically (e.g. by an implanted or wearable devices) or manually collected by the patient using peripheral devices and a transmission hub. RPM interventions for cardiovascular disease (CVD) can be either invasive or non-invasive. Invasive interventions involve direct measurement of biometric data, such as heart rate and pulmonary artery pressures by an implanted device, which are then transmitted to the healthcare provider. Examples of implanted devices include pacemakers which are used to regulate abnormal rhythms, and implantable cardioverter defibrillators (ICDs) which are used in patients at high risk of cardiac arrest (e.g. ventricular tachycardia or fibrillation).[3] Non-invasive interventions involve the transmission of data, such as bodyweight, blood pressure, or pulse oximetry[4] and are used commonly in patients that require long-term self-management support (e.g. patients with heart failure).[5] Review of transmitted data may be active, which occurs when a remote healthcare provider regularly reviews patient data. Alternatively, it may be passive when the healthcare provider is only alerted if data readings reach a pre-determined clinical threshold. Interventions resulting from an abnormal data reading or data indicative of a decline in condition may include telephone support, videoconsultation, or home visits.

Chronic diseases are associated with high rates of unplanned acute hospital use, even more so when the patient has co-morbid conditions.[6] This represents a substantial cost to the health system. For example, in Australia there are more than 748,000 potentially avoidable hospitalizations per year, of which nearly half (46%) were due to chronic conditions such as congestive cardiac failure, diabetes complications, chronic obstructive pulmonary disease (COPD) and angina.[7] Early detection and proactive management of chronic disease exacerbations may result in decreased costly acute hospital use. Previous studies have demonstrated that RPM can effectively alert a healthcare team to a decline in a persons' condition enabling issues to be resolved out of hospital thereby reducing the need for urgent hospital admissions.[8] Existing research shows that for RPM to be cost effective it needs to reduce acute hospital use.[9] There have been a number of disease specific reviews (such as for heart failure and COPD) that have reported effect of RPM on acute hospital use, however this is often a secondary outcome.[5, 10-14] Furthermore, these reviews were largely published more than five years ago. Hence, there is limited evidence for the effect of RPM using newer technologies such as implanted devices and for other disease conditions.[15] With numbers of new RPM technologies substantially increasing in research trials and in the marketplace, more regular reviews of the literature are warranted. The aim of this study is to provide a contemporary evidence synthesis that will determine if the latest RPM tools being used across condition types are reducing acute hospital use.

Methods

In order to achieve the aims of this study we conducted a systematic review of publications from the last five years (2015-2020). Supporting our decision to examine research from the last five years only was a recent systematic review reporting 43% of remote monitoring studies were published from 2015 on, and over 60% of Oxford Level of Evidence 1 papers were published post-2015.[16] The protocol for our review was registered (registration number: CRD42020142523) with the Prospective Register of Systematic Reviews (PROSPERO).[17]

Search strategy

To identify relevant articles we conducted searches of three electronic databases: PubMed (MEDLINE)[1966-2020], EMBASE (OvidSP)[1974-2020], and CINAHL (EBSCOHost)[1982-2020]. Boolean search terms (Box 1) were developed with the assistance of a university librarian and used a combination of medical subject headings (MeSH) and keywords related to remote monitoring, telemedicine, and acute care utilization. Searches were first conducted in July 2019 and updated in October 2020.

Box 1. Example search strategy (PubMed)

("Hospitalization"[Mesh] OR "length of stay"[All Fields] OR ("hospitalization"[All Fields] OR "hospitalization"[MeSH Terms] OR "hospitalization"[All Fields]) OR admission[All Fields] OR presentation[All Fields])

AND

("Remote monitoring"[All Fields] OR "Remote patient monitoring"[All Fields] OR (Inhome[All Fields] AND monitoring[All Fields]) OR "In-home monitoring"[All Fields] OR "Home telehealth"[All Fields] OR Telemonitoring[All Fields] OR Telecare[All Fields])

AND

((Case Reports[ptyp] OR Clinical Study[ptyp] OR Clinical Trial[ptyp] OR Clinical Trial, Phase I[ptyp] OR Clinical Trial, Phase II[ptyp] OR Clinical Trial, Phase III[ptyp] OR Clinical Trial, Phase IV[ptyp] OR Comparative Study[ptyp] OR Controlled Clinical Trial[ptyp] OR Evaluation Studies[ptyp] OR Introductory Journal Article[ptyp] OR Journal Article[ptyp] OR Meta-Analysis[ptyp] OR Multicenter Study[ptyp] OR Observational Study[ptyp] OR Randomized Controlled Trial[ptyp] OR Validation Studies[ptyp])
AND English[lang])

Inclusion/exclusion criteria

We included primary, empirical studies including randomised controlled trials (RCTs), cohort studies, and case control studies that compared acute hospital use by patients undergoing RPM with those not remotely monitored, or studies that compared acute hospital use pre- and post- RPM. Acute hospital use for the purpose of this review is defined as hospital admissions (including readmissions), length of stay, and emergency department (ED) presentations. Patients could be monitored for any disease condition as long as the monitored data was sent to a clinician for review (i.e. self-monitoring was excluded) and the patient was monitored while outside of a hospital setting. A variety of RPM technology was eligible for inclusion such as non-invasive peripheral measurement devices, invasive cardiac implantable electronic devices, and manual data entry using tablets, smartphones, or websites. Only English language articles where the full-text was available were included.

Interventions that did not involve a disease condition (e.g. those with a focus on monitoring physical activity) were excluded. Studies that used simulated or modelled data were excluded, as were reviews, non-experimental studies, conference abstracts, and commentaries.

Selection

Titles and abstracts were screened independently by two researchers (MT, MB) who were also blinded to each other's selections. Where necessary the full text was used to determine eligibility. A third researcher (CS, ET, or LC) decided on inclusion when consensus was not reached.

Data extraction

Data was extracted from the full text of the articles and recorded on a data extraction form. A description of data extraction variables can be found in Table 1. One author (MT) extracted the data and a second author (ET) validated the accuracy by checking a 20% random selection of the data.

Table 1 Extracted variables

Variable	Description
First Author	Surname of the first author of the publication
Year	Year of publication
Country	Country where research was conducted
Study Type	Study design as cohort, RCT, quasi-experimental, or case-control
Patient Group	Medical condition of study participants
Comorbidities	Whether or not the authors mentioned participants having comorbidities
Data being monitored	Patient vitals measured using remote monitoring (e.g. BP, heart rate, etc.)
Trial length	Length of time a patient was remotely monitored (number of months)
Sample size	Number of participants in the research, listed by intervention and control groups
Mean age	The average or mean age of the intervention and control groups as reported by authors
Gender split	Percentage of male and female participants in the study
RPM Device	Device used for remote monitoring (e.g. tablet, dedicated RM unit, etc.)
Data collection	Whether biometric data was collected manually or automatically
Data review	Whether biometric data was reviewed by clinical staff passively (e.g. there was an automated alert system) or actively (e.g. nurse checks dashboard each day)
Supplementary support mode	If support from clinical staff beyond event management or routine visits occurred, what was the mode of contact used
Outcome type	Whether the outcome reported was for all cause, condition-specific, both, or not specified
Outcome findings	Results of the investigation (significant or not significant increase or decrease in acute care use and effect size where available)
Summary	Overall summary of whether RM increased, decreased, or had no significant effect on acute care use in the study

Quality assessment

Quality of the included studies was assessed using The Joanna Briggs Institute (JBI) critical appraisal checklists.[18] This suite of checklists has individual templates based on study design. Specific checklists have different numbers of questions. The appropriate checklist was chosen using an algorithm for classifying study design.[19] To allow comparison across study design, the number of checklist items that received a "yes" was converted to a proportion of the total number of questions. Based on the "yes" proportions, studies were categorised as high (80% and over), medium (60-79%), or low (<60%) quality.

Two researchers (MT, ET) completed quality assessment on each article and scores were compared and consensus reached via discussion. When a publication reported outcomes both related and not related to acute case use, the quality assessment score was based on the measurement of the acute care use outcomes specifically. No articles were excluded from this review based on their quality score.

Analysis

Findings from included article were stratified by acute care use as admissions, ED presentations or length of stay. Findings were categorised by the author's conclusion on increased, decreased, or no change on acute hospital use. Changes in use that were not statistically significant were categorised as no change. Subgroup analysis was undertaken on disease condition and technology category permutations (i.e. invasive versus non-invasive).

Due to the heterogeneity in population groups, intervention designs and outcome measures findings were synthesized narratively. Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[20]

Results

Study selection

Ninety-one articles were included in this review. The results of each stage of search and selection process are shown in the PRISMA diagram (Figure 1).

[INSERT FIGURE 1]
Figure 1. PRISMA flow diagram of screening process and study selection

Study characteristics

Included studies were primarily conducted in Europe (n = 52, 57%), followed by the United States (n=26, 29%). Most studies were randomized controlled trials (RCTs) (n=45, 50%) or cohort studies (n=34, 37%), with nine quasi-experimental studies (10%) and three case-controls (3%).

The sample size of patients ranged from 25 [21] to 92,566 [22] with the majority of included studies (n=68, 75%) having a sample size of greater than 100 participants (intervention and control arms combined). Follow-up time was longer than six months in the majority of studies (n=62, 68%), however, 12% (n=11) had a follow-up time of three months or less. Thirty-two studies (35%) included >70% male participants. Gender bias was commonly observed in many CVD trials despite similar numbers of deaths across both genders.[23, 24] All interventions, except one study on infants with heart disease, were targeted at adults. Acute hospital use was reported for all causes (n=18,

20%), only the remotely monitored condition (n=21, 23%), both the all cause and the disease-specific condition (n=30, 33%), or was not specified (n=22, 24%).

Characteristics of all included studies are summarized in Supplementary Table 1.

Intervention characteristics

Disease conditions

The patient populations in the included studies were mostly people with CVD (n=54, 59%), COPD (n=18, 20%) or co-morbid CVD and COPD (n=4, 4%). Of these, invasive monitoring was used for 22 studies and non-invasive monitoring was used in 30 studies. Remaining studies (n=15, 17%) had varying study populations including nursing home residents, patients with schizophrenia, peritoneal dialysis patients, inflammatory bowel disease, and individuals on home ventilation.

Remote monitoring processes

The most common biometrics that were remotely monitored were heart rate (n=52, 57%), blood pressure (n=49, 54%), weight (n=44, 48%), and oxygen saturation (n=39, 43%). Cardiac implantable electronic devices (CIEDs) (n=22, 24%) can enable automated transmission of data, monitor heart rhythm, alert if an arrhythmic episode occurs and check the device function.

A comparison of data being monitored in each study can be seen in Supplementary Table 2.

The non-invasive interventions (n=69, 76%) required manual data collection performed by the patient or support person. Clinical review of biometrics was evenly split between those that had passive review (i.e. automated alert) and those that had active data review (e.g. clinician logging into system to review patient data daily). Typically, manual data collection was actively reviewed by a nurse or other clinician once per day.

In all studies out-of-range biometrics triggered clinical communication. Some interventions involved supplementary services from staff, such as assisting with education and health literacy. Modes of communication with patients included telephone (n=37, 41%), videoconference (n=13, 14%), and asynchronous methods such as SMS or email (n=10, 11%).

Technology

The technology for RPM was either a dedicated unit or hub (n=35, 39%); CIEDs including ICDs, cardiac resynchronization therapy (CRT) including those with defibrillators (CRT-Ds), and pacemakers (n=22, 24%); tablet computers application (n=13, 14%); or telephone or smartphone app (n=9, 10%); websites (n=4, 4%); or other technologies such as an electronic health diary, inhaler, or medication device (n=8, 9%). Forty studies explicitly stated the patient used peripheral devices such as weight scales, pulse oximeters, and thermometers.

Effect of remote monitoring on acute care use

RPM for all disease conditions was reported to have reduced admissions, length of stay and ED presentations in 49% (n=44 of 90), 49% (n=23 of 47), and 41% (n=13 of 32) of studies respectively for studies that reported each measure of acute care use. The remaining studies largely reported no change in acute care use for remotely monitored patients. A very small number of studies reported RPM increased acute care use (Figures 2, 3, 4). The majority of studies set a significance level of 5% for concluding that there was a difference between groups, however individual study details on this can be viewed in Supplementary Table 1.

[Insert Figure 2]
Figure 2. Effect of RPM on hospitalisation by condition type

[Insert Figure 3]
Figure 3. Effect of RPM on length of stay by condition type

[Insert Figure 4]
Figure 4. Effect of RPM on ED presentations by condition type

CVD invasive

CVD using invasive monitoring appears to be most effective at reducing hospitalizations (Figure 2). Eleven RCTs have been conducted.[25-35] Of these, only three demonstrated a significant reduction in acute care use with a reduction in length of hospital stays[26] by 2.5 days (RPM = 10.3 ± 8.1 days, median: 8.0 days vs. non-monitored group = 17.5 ± 19.9 days, median 10.5 days, *p* = 0.027) and lower hospitalisation rates in the monitored group (37.1% vs 45.5%, p = 0.045;[31] hazard ratio 0.6, 0.42-0.79, p=0.002[35]). All remaining RCTs (n=6, 55%) showed no significant effect. Of the eight cohort studies conducted with invasive monitoring, five (63%) showed a significant reduction in hospital use. Two of these[22, 36] had very large sample sizes with matched controls (n=37,742 and 92,566 respectively). In fact, Piccini et al. [22], had a larger sample size (n=92,566) than all the other CVD invasive populations combined (n=49,113). Both Piccini et al. [22] and Akar et al. [36] reported an 18% lower risk of all-cause hospitalization in the RPM groups with both studies reporting identical adjusted hazard ratios of 0.82 (95% CI: 0.80 – 0.84; p-value: <0.001). Piccini et al. [22] also reported a shorter mean length of hospital stay of approximately three days (5.3 days vs. 8.1 days; P<0.001). These reductions were preserved for all implanted device types (pacemakers, ICDs and CRT) but were maximal in CRT participants. By contrast Ladapo et al.[37] reported the most pronounced benefits of hospital use in patients with ICDs.

CVD non-invasive

Most RCTs investigating the impact of non-invasive RPM were for heart failure populations (n=15, 37%). Findings from these studies have been mixed with eight trials (53%) reporting no difference and seven trials (47%) reporting a reduction in acute hospital use. The largest RCT included in this review reported the RPM group spent approximately two days less in hospital compared to control participants (RPM group = mean 3.8 days per year, 95% CI: 3.5–4.1 vs 5.6 days per year 95% CI: 5·2–6·0).[38] However, similarly large RCTs reported no change in the number of hospitalizations or length of stay.[39, 40] Studies varied in regard to the precise population investigated, the duration of RPM, the type of devices used, and the intensity and timing of the interaction. Koehler et al. provided the first structured RPM intervention that used a holistic approach including multiple healthcare providers (e.g. cardiologist, GP, nurse) and tailored support using a predefined algorithm.[38]

COPD

RPM of COPD appears to be most effective at reducing ED presentations (Figure 4). Of the 13 RCTs investigating RPM in COPD populations, seven trials (54%) showed no significant difference in hospital use between the intervention and control groups and approximately 30% reported a reduction in hospital use. Two reported an increase in hospital admissions in the RPM group;[41,42] Udsen et al.[42] had the largest sample size (n=578/647 intervention/control) of the trials. Across the RCTs, COPD-related hospitalizations differed from a mean difference of ten fewer admissions in the

intervention group of Sink et al.[43] over eight months (absolute risk reduction=11.6%; RPM = 6 hospitalizations vs. non-monitored = 16 hospitalizations) to a slight increase in admissions over a six month period (RPM admissions = 0.63 vs. 0.32 in non-monitored mean difference: 0.32, p-value: 0.026). [41] All cohort studies (n=9) reported a reduction in at least one measure of acute hospital use. Of these the largest sample size (n=651/7047 intervention/control) and over a 12-month period reported a lower proportion of patients hospitalized due to all-causes (−15.16%, $p < 0.0001$), and COPD-specific admissions (−20.27%, $p < 0.0001$). [44] On average, people in the RPM group spent 3.1 ($p < 0.0001$) and 2.07 ($p < 0.001$) fewer days in hospital due to all causes and COPD, respectively, than the control group.

Other conditions

The current RPM literature to date is dominated by adult CVD and COPD populations. It is worth noting that beneficial effects of RPM have been observed in some other conditions. Notably, one study demonstrated a significant reduction in hospital admission among infants with single ventricular heart disease (relative risk of hospital use in the control group: 2.19, 95% CI: 1.16-4.12, P = .016). [45] Reductions in hospital use were also seen in RPM groups with multiple chronic conditions ;[46] mental health; [47,48] and patients with home-ventilated neuromuscular conditions.[49]

Study quality

The overall quality of studies as assessed by the Joanna Briggs Institute critical appraisal checklists was medium to high (**Error! Reference source not found.**5).[18] The quality of RCTs was most often compromised by participant outcomes being assessed by someone who was not blinded to the control or intervention group. However, it can be challenging to blind an assessor or participant in this type of intervention. In cohort studies, the quality was compromised by incomplete follow. Only one third of the studies had clearly done so, while the remaining two thirds either did not address incomplete follow up or it was unclear.

[Insert Figure 5]

Figure 5. Number of articles by proportion of "Yes" responses to items on the Joanna Briggs Institute critical appraisal checklists, separated by study type

Discussion

Principal findings

This systematic review found around half of 91 included studies reported RPM decreased hospital admissions and around half reported no change. A smaller number of studies reported the effect of RPM on length of stay (n=47) and ED presentations (n=32), with around half reporting a decrease and half reporting no change for both of these measures of acute hospital use. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Similarly, invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease conditions and non-invasive monitoring. Only four studies reported higher acute hospital use resulting from RPM.[32, 41, 42, 50] Around 70% of included studies were for CVD, COPD or co-morbid CVD and COPD. RPM for lesser studied populations including mental health and neuromuscular conditions, appears feasible but findings on acute hospital use is inconclusive due to the limited number of studies. Study quality as appraised by the JBI critical appraisal checklist was considered medium to high.

A strength of this study when compared to other reviews was the inclusion of all disease conditions, monitoring types and study designs. The broad inclusion categories has allowed analysis of RPM on disease conditions beyond those published on heart failure, previously excluded studies (e.g. cohort studies), and comparison of effectiveness of different RPM interventions. Whilst RCTs are considered the gold-standard experimental design, restricting to RCTs excludes large scale cohort studies, which can provide both strong evidence and are more applicable to real-world settings. For example, the Parthiban et al. [3] meta-analysis is, to the best of our knowledge, the only review that reports the impact on hospital admissions resulting from invasive cardiac monitoring. This study found no significant reduction in admissions, however, findings from a large scale cohort study (n=34,259/58,307 intervention/control) by Piccini et al.[22] found that invasive cardiac monitoring significantly reduced both all-cause hospitalizations and the resultant length of stay

There has been a number of previous reviews of RPM for COPD populations.[13, 15] One included six primary studies (both RCTs and other study designs) of which four reported reduction in hospital admissions.[15] Our review included 22 studies on RPM of COPD and co-morbid COPD populations. Our findings were consistent when comparing the effect on hospital admissions. However, in addition we found a reduction in ED presentations in around half of the studies. Two of the four studies that reported RPM resulted in increased acute care use were in COPD population. This increase may explained by the perception that predicting COPD exacerbations based on variations in spirometry and other physiological measures continues to be a challenge resulting in high rates of false positive warnings in this cohort.[44]

Implications for practice

Effect of RPM on sub-populations

Clinical outcomes for patients on remote monitoring have been more effective for sub-populations when compared to the whole of population. The largest study to date, [22] reported that RPM was associated with reductions in all-cause hospitalization. While this association held across all implanted devices, it was most evident for cardiac resynchronization therapy patients, suggesting that sicker patients are the most likely to benefit. Furthermore, the greater effectiveness of invasive RPM may result from the continuous generation of biometric measurements. Whereas, non-invasive monitoring produces intermittent measurements. The safety of implanted devices can also be checked remotely using RPM to identify any device or lead malfunctions earlier.[36] Notably, no study in this review reported adverse events related to patient safety. This review has also demonstrated that the way remote monitoring services are implemented are highly variable and intervention characteristics could be a determinant of outcomes. For example, patients using smartphone apps were shown to have better compliance to monitoring than those using a web page.[51] Further to this, the severity of disease can also be a determining factor of how effective an RPM intervention will be in reducing acute care use.[13]

Importance of a patient-centric approach

RPM interventions are complex and require careful patient selection along with appropriate technology that accurately alerts healthcare staff and results in a timely response. Additionally, how RPM might improve a patient's health literacy and self-efficacy to manage their condition is likely to be highly important.[52] Supportive of this theory is one author who postulated this was due to participants becoming dependant on the RPM systems and telemonitoring nurse rather than developing the appropriate skills to self-manage. [53] A patient-centred approach that enables seamless interaction between patients and the healthcare system is likely to influence RPM success. This is demonstrated well by the comprehensive approach Koehler et al. [38] took by involving

multiple healthcare providers (e.g. cardiologist, GP, nurse) and using an algorithm to tailor support to participants resulting in positive results for people with heart failure.

Many studies reported that RPM increased quality of life, improved the timeliness of atrial fibrillation detection and improved communication.[5, 12, 40, 54] Focusing on effect of acute care use, may result in overlooking ancillary benefits of RPM.

There appears to be a lack of studies for some highly prevalent chronic conditions such as diabetes. This may be explained by the fact that exacerbation of diabetes is less likely to result in acute hospital use relative to CVD or COPD; and therefore studies on the effect of remote monitoring of diabetes do not use acute hospital use as an outcome measure.

Limitations

Findings of this review should be interpreted in light of some limitations. First, publication bias is possible with selective reporting of studies with findings of reduced acute hospital use. The included studies were highly heterogeneous in terms of patient groups (e.g. co-morbidities), intervention (e.g. inclusion of educational component, invasive versus non-invasive monitoring, active versus passive review) and study differences (e.g. all-cause *versu*s disease-specific acute hospital use). This makes generalizability of findings difficult. Due to heterogeneity and inability to perform a meta-analysis we used proportion of studies reporting a decrease in acute hospital use as a measure of comparative effectiveness. Differences in the control population may also lead to very different rates of admissions and influence whether or not a significant effect is found. For example, Boriani et al. [34] compared two trials found that one year mortality in the control-arm of each trial differed by nearly a factor of two. Finally, a study that uses patient self-reported acute hospital use may be less rigorous than those that used a retrospective approach supported by activity data, due to patient recall bias. [55]

Future research

Further investigation is needed to identify sub-populations and intervention characteristics that will enhance the effectiveness of remote monitoring. Policy makers and funders also need to understand if remote monitoring is cost effective. It is important for implementation of RPM interventions to consider costs from a system perspective. It would be wrong to assume that reducing admissions reduces costs, as there is potential of increasing collateral health system usage (e.g. to outpatient care). Economic analysis is also needed to consider the cost of implementing and operating RPM interventions as opposed to only comparing the direct cost of acute care use.[56]

Conclusion

This review has shown that RPM of CVD and COPD can reduce hospital admissions, length of stay, and emergency presentation in around half of interventions and results in no change in acute care usage in the remaining. Increased acute care use was rarely reported. The effect of RPM for other disease conditions is inconclusive due to the limited number of studies in these areas. Clinical outcomes for patients on remote monitoring have been more effective for sub-populations when compared to the whole of population. RPM of COPD was more effective at reducing ED presentation than RPM of other disease conditions. Invasive monitoring of CVD was more effective at reducing hospital admissions compared to other disease conditions and non-invasive monitoring. This may be in part due to the ability of implantable devices to continuously monitor a person and automatically transmit data. Implantable devices have advanced ability to directly detect cardiac issues (e.g. atrial fibrillation) rather than relying on physiological signs (e.g. changes in weight or blood pressure) that

may or may not be due to the underlying cardiac condition. Further research is required to understand the underlying mechanisms causing such variation in RPM studies. Findings from this review should be considered alongside other benefits of RPM including increased quality of life and autonomy for patients.

Acknowledgements

The authors would like to thank Julie Hansen, Senior Librarian from UQ Library for her assistance in developing the search strategy for this systematic review. They would also like to thank Ms Maryama Bihi for her assistance in screening titles and abstracts.

Conflict of Interest Statement

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Funding

This research is conducted for the NHMRC Partnership Centre for Health System Sustainability (Grant ID #: 9100002) administered by the Australian Institute of Health Innovation, Macquarie University. Along with the NHMRC, the funding partners in this research collaboration are: The Bupa Health Foundation; NSW Ministry of Health; Department of Health, WA; and The University of Notre Dame Australia. Their generous support is gratefully acknowledged.

While the NHMRC, The Bupa Health Foundation, NSW Ministry of Health, Department of Health, WA and The University of Notre Dame Australia, have provided in-kind and financial support for this research, they have not reviewed the content and are not responsible for any injury, loss or damage however arising from the use of, or reliance on, the information provided herein. The published material is solely the responsibility of the authors and does not reflect the views of the NHMRC or its funding partners.

ET is supported by a Postdoctoral Fellowship (105215) from the National Heart Foundation of Australia.

Contributorship Statement

This research was conceptualised by LC. MT, ET, CS, AS and LC contributed to the study design. Searches and data extraction were carried out by MT and ET under guidance from CS and LC. Data analysis was performed by MT, ET, and LC. Manuscript was drafted by MT, ET, and LC. Critical review of manuscript was undertaken by all authors. All authors approved the final manuscript.

Patient Involvement Statement

This research was done without patient involvement. Patients were not invited to comment on the study design and were not consulted to develop patient relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

Data Availability Statement

All data relevant to the study are included in the article or uploaded as supplementary information.

References

1. The American Telemedicine Association. Telemedicine, Telehealth, and Health Information Technology 2006. Accessed: 3 December 2020. Available at: https://www.who.int/goe/policies/countries/usa_support_tele.pdf?ua=1
2. Malasinghe LP, Ramzan N and Dahal K. Remote patient monitoring: a comprehensive study. *Journal of Ambient Intelligence and Humanized Computing*. 2019; 10(1): 57-76.
3. Parthiban N, Esterman A, Mahajan R, et al. Remote monitoring of implantable cardioverter-defibrillators: a systematic review and meta-analysis of clinical outcomes. *Journal of the American College of Cardiology*. 2015; 65(24): 2591-600.
4. Vegesna A, Tran M, Angelaccio M, et al. Remote patient monitoring via non-invasive digital technologies: a systematic review. *Telemedicine and e-Health*. 2017; 23(1): 3-17.
5. Inglis SC, Clark RA, McAlister FA, et al. Which components of heart failure programmes are effective? A systematic review and meta-analysis of the outcomes of structured telephone support or telemonitoring as the primary component of chronic heart failure management in 8323 patients: abridged Cochrane review. *European journal of heart failure*. 2011; 13(9): 1028-40.
6. Hernandez C, Jansa M, Vidal M, et al. The burden of chronic disorders on hospital admissions prompts the need for new modalities of care: a cross-sectional analysis in a tertiary hospital. *QJM: An International Journal of Medicine*. 2009; 102(3): 193-202.
7. Australian Institute of Health and Welfare. Potentially preventable hospitalizations in Australia by small geographic areas. 2019. AIHW. Accessed. Available at: https://www.aihw.gov.au/reports/primary-health-care/potentially-preventable-hospitalisations/contents/overview
8. Landolina M, Perego GB, Lunati M, et al. Remote monitoring reduces healthcare use and improves quality of care in heart failure patients with implantable defibrillators: the evolution of management strategies of heart failure patients with implantable defibrillators (EVOLVO) study. *Circulation*. 2012; 125(24): 2985-92.
9. Seto E. Cost comparison between telemonitoring and usual care of heart failure: a systematic review. *Telemedicine and e-Health*. 2008; 14(7): 679-86.
10. Bashi N, Karunanithi M, Fatehi F, et al. Remote monitoring of patients with heart failure: an overview of systematic reviews. *Journal of medical Internet research*. 2017; 19(1): e18.
11. Conway A, Inglis SC, Chang AM, et al. Not all systematic reviews are systematic: a meta-review of the quality of systematic reviews for non-invasive remote monitoring in heart failure. *Journal of telemedicine and telecare*. 2013; 19(6): 326-37.
12. Purcell R, McInnes S and Halcomb EJ. Telemonitoring can assist in managing cardiovascular disease in primary care: a systematic review of systematic reviews. *BMC family practice*. 2014; 15(1): 43.
13. Hong Y and Lee SH. Effectiveness of tele-monitoring by patient severity and intervention type in chronic obstructive pulmonary disease patients: a systematic review and meta-analysis. *International journal of nursing studies*. 2019; 921-15.
14. Kruse C, Pesek B, Anderson M, et al. Telemonitoring to manage chronic obstructive pulmonary disease: systematic literature review. *JMIR medical informatics*. 2019; 7(1): e11496.
15. Bolton CE, Waters CS, Peirce S, et al. Insufficient evidence of benefit: a systematic review of home telemonitoring for COPD. *Journal of evaluation in clinical practice*. 2011; 17(6): 1216-22.
16. Farias FACd, Dagostini CM, Bicca YdA, et al. Remote Patient Monitoring: A Systematic Review. *Telemedicine and e-Health*. 2020; 26(5): 576-83.
17. PROSPERO International prospective register of systematic review. The impact of remote patient monitoring on acute hospital use. 2020. National Institute for Health Research,. Accessed. Available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=142523

18. Joanna Briggs Institute. Critical Appraisal Tools. 2020. University of Adelaide. Accessed. Available at: https://joannabriggs.org/ebp/critical_appraisal_tools
19. The National Institute for Health and Care Excellence (NICE) and the Scottish Intercollegiate Guidelines Network (SIGN). Algorithm for classifying study design for questions of effectiveness. Unknown year. Accessed: 22 April 2020. Available at: https://www.sign.ac.uk/assets/study_design.pdf
20. PRISMA. Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2015. Accessed. Available at: http://www.prisma-statement.org/
21. Hale TM, Jethwani K, Kandola MS, et al. A Remote Medication Monitoring System for Chronic Heart Failure Patients to Reduce Readmissions: A Two-Arm Randomized Pilot Study. *Journal of medical Internet research*. 2016; 18(5): e91.
22. Piccini JP, Mittal S, Snell J, et al. Impact of remote monitoring on clinical events and associated health care utilization: A nationwide assessment. *Heart rhythm*. 2016; 13(12): 2279-86.
23. Mehran R, Vogel B, Ortega R, et al. The Lancet Commission on women and cardiovascular disease: time for a shift in women's health. *The Lancet*. 2019; 393(10175): 967-8.
24. The Lancet. Cardiology's problem women. *The Lancet*. 2019; 393(10175): 959.
25. Amara W, Montagnier C, Cheggour S, et al. Early Detection and Treatment of Atrial Arrhythmias Alleviates the Arrhythmic Burden in Paced Patients: The SETAM Study. *Pacing and clinical electrophysiology : PACE*. 2017; 40(5): 527-36.
26. Bulava A, Ošmera O, Šnorek M, et al. Cost analysis of telemedicine monitoring of patients with implantable cardioverter-defibrillators in the Czech Republic. *Cor et Vasa*. 2016; 58(3): e293-e302.
27. Geller JC, Lewalter T, Bruun NE, et al. Implant-based multi-parameter telemonitoring of patients with heart failure and a defibrillator with vs. without cardiac resynchronization therapy option: a subanalysis of the IN-TIME trial. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2019; 108(10): 1117-27.
28. Hansen C, Loges C, Seidl K, et al. INvestigation on Routine Follow-up in CONgestive HearT FAilure Patients with Remotely Monitored Implanted Cardioverter Defibrillators SysTems (InContact). *BMC cardiovascular disorders*. 2018; 18(1): 131.
29. Heidbuchel H, Hindricks G, Broadhurst P, 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. *European heart journal*. 2015; 36(3): 158-69.
30. Luthje L, Vollmann D, Seegers J, et al. A randomized study of remote monitoring and fluid monitoring for the management of patients with implanted cardiac arrhythmia devices. *Europace*. 2015; 17(8): 1276-81.
31. Tajstra M, Sokal A, Gadula-Gacek E, et al. Remote Supervision to Decrease Hospitalization Rate (RESULT) study in patients with implanted cardioverter-defibrillator. *EP Europace*. 2020; 22(5): 769-76.
32. Zakeri R, Morgan JM, Phillips P, et al. Impact of remote monitoring on clinical outcomes for patients with heart failure and atrial fibrillation: results from the REM-HF trial. *European journal of heart failure*. 2020; 22(3): 543-53.
33. Böhm M, Drexler H, Oswald H, et al. Fluid status telemedicine alerts for heart failure: A randomized controlled trial. *European Heart Journal*. 2016; 37(41): 3154-63.
34. Boriani G, Da Costa A, Quesada A, 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. *European journal of heart failure*. 2017; 19(3): 416-25.
35. Sardu C, Santamaria M, Rizzo MR, et al. Telemonitoring in heart failure patients treated by cardiac resynchronisation therapy with defibrillator (CRT-D): the TELECART Study. *International journal of clinical practice*. 2016; 70(7): 569-76.

36. Akar JG, Bao H, Jones PW, et al. Use of Remote Monitoring Is Associated With Lower Risk of Adverse Outcomes Among Patients With Implanted Cardiac Defibrillators. *Circulation Arrhythmia and electrophysiology*. 2015; 8(5): 1173-80.
37. Ladapo JA, Turakhia MP, Ryan MP, et al. Health Care Utilization and Expenditures Associated With Remote Monitoring in Patients With Implantable Cardiac Devices. *The American journal of cardiology*. 2016; 117(9): 1455-62.
38. Koehler F, Koehler K, Deckwart O, et al. Efficacy of telemedical interventional management in patients with heart failure (TIM-HF2): a randomised, controlled, parallel-group, unmasked trial. *The Lancet*. 2018; 392(10152): 1047-57.
39. Kalter-Leibovici O, Freimark D, Freedman LS, et al. Disease management in the treatment of patients with chronic heart failure who have universal access to health care: A randomized controlled trial. *BMC Medicine*. 2017; 15(1).
40. Ong MK, Romano PS, Edgington S, et al. Effectiveness of Remote Patient Monitoring After Discharge of Hospitalized Patients With Heart Failure: The Better Effectiveness After Transition -- Heart Failure (BEAT-HF) Randomized Clinical Trial. *JAMA internal medicine*. 2016; 176(3): 310-8.
41. Chatwin M, Hawkins G, Panicchia L, et al. Randomised crossover trial of telemonitoring in chronic respiratory patients (TeleCRAFT trial). *Thorax*. 2016; 71(4): 305-11.
42. Udsen FW, Lilholt PH, Hejlesen O, et al. Cost-effectiveness of telehealthcare to patients with chronic obstructive pulmonary disease: Results from the Danish TeleCare North' cluster-randomised trial. *BMJ Open*. 2017; 7(5): e014616.
43. Sink E, Patel K, Groenendyk J, et al. Effectiveness of a novel, automated telephone intervention on time to hospitalisation in patients with COPD: A randomised controlled trial. *J Telemed Telecare*. 2018; 26(3): 132-9.
44. Achelrod D, Schreyogg J and Stargardt T. Health-economic evaluation of home telemonitoring for COPD in Germany: evidence from a large population-based cohort. *The European journal of health economics : HEPAC : health economics in prevention and care*. 2017; 18(7): 869-82.
45. Bingler M, Erickson LA, Reid KJ, et al. Interstage Outcomes in Infants With Single Ventricle Heart Disease Comparing Home Monitoring Technology to Three-Ring Binder Documentation: A Randomized Crossover Study. *World Journal for Pediatric and Congenital Hearth Surgery*. 2018; 9(3): 305-14.
46. Celler B, Varnfield M and Jayasena R. What Have We Learned from the CSIRO National NBN Telehealth Trial? *Studies in health technology and informatics*. 2018; 2461-17.
47. De Luca R, Bramanti A, De Cola MC, et al. Tele-health-care in the elderly living in nursing home: the first Sicilian multimodal approach. *Aging clinical and experimental research*. 2016; 28(4): 753-9.
48. Flaherty LR, Daniels K, Luther J, et al. Reduction of medical hospitalizations in veterans with schizophrenia using home telehealth. *Psychiatry research*. 2017; 255153-5.
49. Trucco F, Pedemonte M, Racca F, et al. Tele-monitoring in paediatric and young home-ventilated neuromuscular patients: A multicentre case-control trial. *Journal of telemedicine and telecare*. 2019; 25(7): 414-24.
50. D'Ancona G, Safak E, Senges J, et al. Activation of remote monitoring for cardiac implantable electronic devices: small dog for tall weeds. *Clinical research in cardiology : official journal of the German Cardiac Society*. 2017; 106(10): 833-9.
51. Schreier G, Eckmann H, Hayn D, et al. Web versus App - compliance of patients in a telehealth diabetes management programme using two different technologies. *Journal of telemedicine and telecare*. 2012; 18(8): 476-80.
52. Bohingamu Mudiyanselage S, Stevens J, Watts JJ, et al. Personalised telehealth intervention for chronic disease management: A pilot randomised controlled trial. *Journal of telemedicine and telecare*. 2019; 25(6): 343-52.

53. Agboola S, Jethwani K, Khateeb K, et al. Heart failure remote monitoring: evidence from the retrospective evaluation of a real-world remote monitoring program. *Journal of medical Internet research*. 2015; 17(4): e101.
54. Klersy C, De Silvestri A, Gabutti G, et al. Economic impact of remote patient monitoring: an integrated economic model derived from a meta-analysis of randomized controlled trials in heart failure. *European journal of heart failure*. 2011; 13(4): 450-9.
55. Nancarrow S, Banbury A and Buckley J. Evaluation of a National Broadband Network-enabled Telehealth trial for older people with chronic disease. *Australian Health Review*. 2016; 40(6): 641-8.
56. Peretz D, Arnaert A and Ponzoni NN. Determining the cost of implementing and operating a remote patient monitoring programme for the elderly with chronic conditions: A systematic review of economic evaluations. *Journal of telemedicine and telecare*. 2018; 24(1): 13-21.

Figures

Supplementary Information

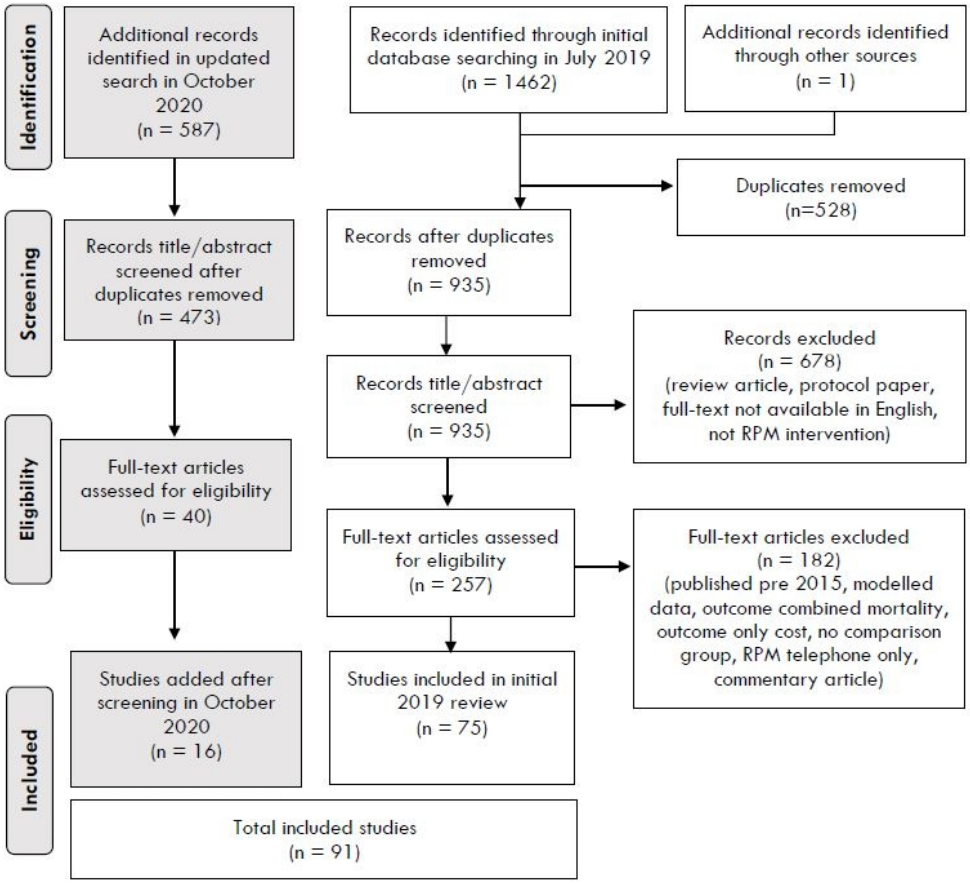

Figure 1. PRISMA flow diagram of screening process and study selection. (RPM= remote patient monitoring)

205x184mm (96 x 96 DPI)

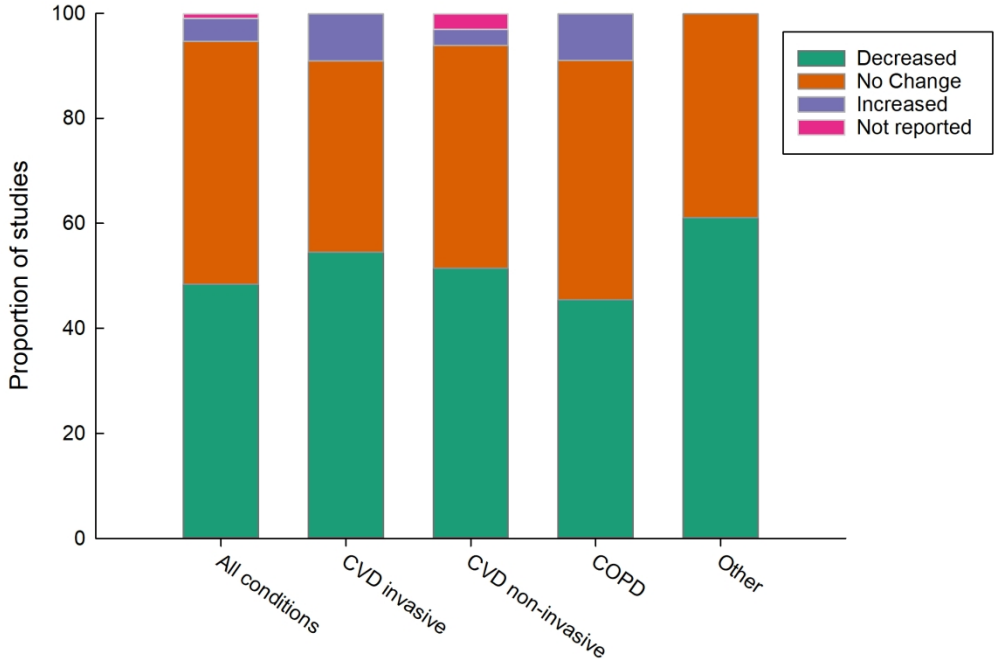

Figure 2. Effect of RPM on hospitalisations by condition type

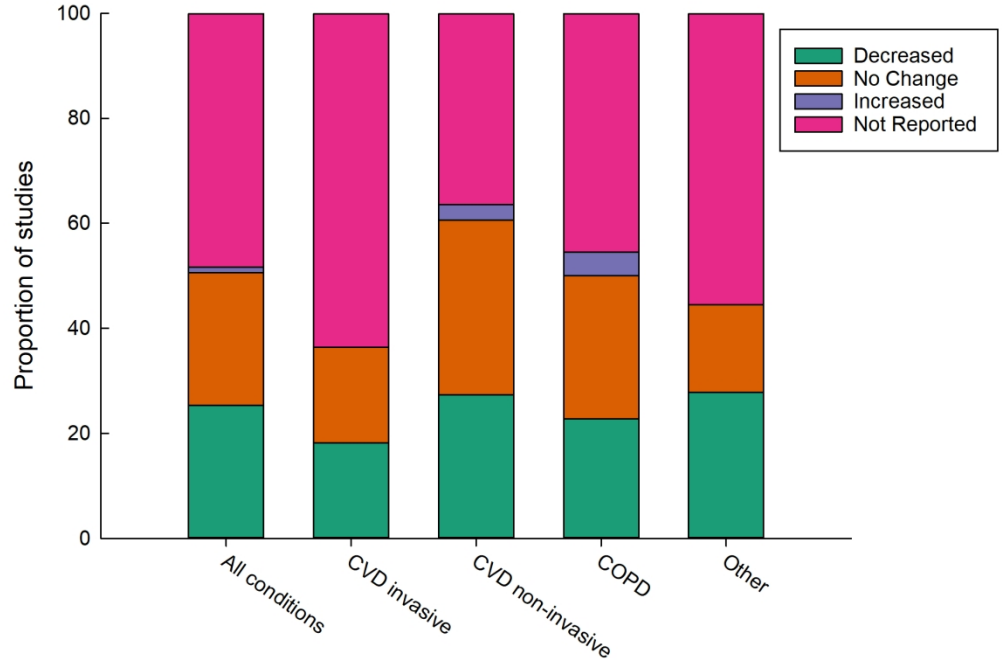

Figure 3. Effect of RPM on length of stay by condition type

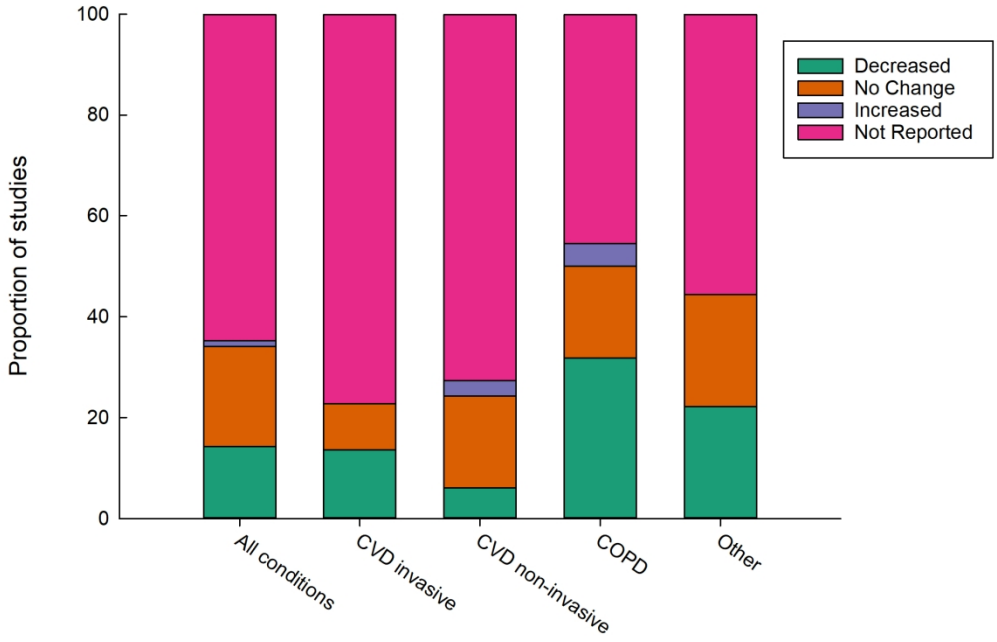

Figure 4. Effect of RPM on ED presentations by condition type

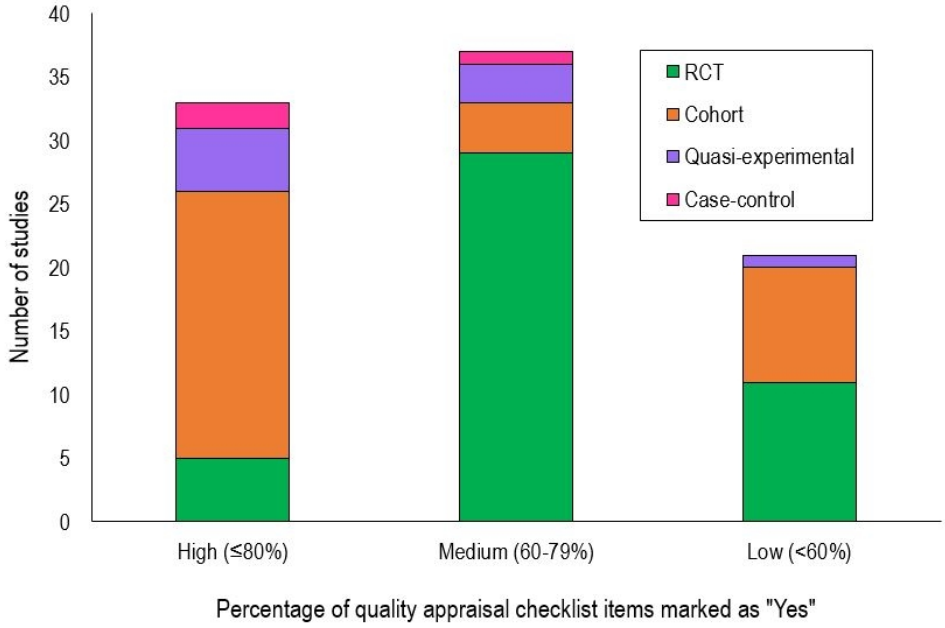

Figure 5. Number of articles by proportion of "Yes" responses to items on the Joanna Briggs Institute critical appraisal checklists, separated by study type

226x156mm (96 x 96 DPI)

Supplementary Table 1. Characteristics of included studies

First Author, Year (Country)	Study type	Patient group	Trial length (approx. months)	Sample size (close out if avail)	Average/Mean age	M/F split	RPM device	Data collection type	Data review type (Active, Passive - alert)	Supplementary support modes	OUTCOME: All cause, condition-specific, both, or not specified	Outcome findings as reported by authors in article	Summary of RPM effect on acute care use
Achelrod, 2017 (Germany)	Cohort	COPD	Baseline 24, Follow up 12	651 intervention; 7047 control	64.24 (Int); 69.47 (control before); 64.24 (control after)	43.93% female (Int); 49.17 (control before); 43.93 (control after)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	Hospitalisations due to all causes (-15.16 %, p<0.0001), due to COPD (-20.27 %, p<0.0001) and COPD-related ED presentations (-17.00 %, p<0.0001) were consistently lower in RPM patients, leading to fewer all-cause (-0.21, P<0.0001), COPD-related (-0.18, p\0.0001) and COPD-related ED presentations (-0.14, P<0.0001). On average, people in RPM group spent 3.1 (P<0.0001) and 2.07 (P<0.001) fewer days in hospital due to all causes and COPD, respectively, than control group.	Decreased
Agboola, 2015 (USA)	Cohort	Heart failure	4	174 intervention; 174 control	76.66 (10.71 SD) (Int); 76.76 (10.71 SD) (control)	58.62% male (Int & control)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Compared with controls, hospitalisation rates decreased within first 30 days of program enrollment (HR = 0.52, 95% CI 0.31-0.86, P=.01); Mean LOS similar in both groups (7 (8.92) RPM vs. 8 (8.83) control, P = 0.92).	Decreased hospitalisation, no significant difference in LOS
Akar, 2015 (USA)	Cohort	Patients with CIEDs (unspecified)	6	20852 intervention; 16890 control	67.5 (SD 12.1, 21-89) (Int); 66.5 (SD 13.0, 21-89) (control)	70.9% male (Int); 72.6% male (control)	CIED	Automatic	Passive	Not stated	All-cause	Risk of rehospitalisation of RPM patients (n=9150, 60%) lower than those not using RPM (HR= 0.82, 95% CI 0.80–0.84, P<0.0001).	Decreased
Alshabani, 2019 (USA)	Cohort	COPD	12	39	68.6 (9.9)	M:F 20:19	Electronic inhaler monitoring device	Automatic	Passive	Not stated	All-cause and condition-specific	RPM associated with reduction in COPD-related ED presentations and hospitalisations combined per year - 2.2 (± 2.3) vs. 3.4 (± 3.2), p=0.01. All-cause this was also was reduced, although difference was NS (3.4 (2.6) vs. 4.7 (4.1), P = 0.06).	Decreased condition-specific, no significant difference all-cause
Amara, 2017 (France)	RCT	Patients with CIEDs (unspecified)	12	291 intervention; 304 control	79 (±8) (all, Int, and control)	63% male (all); 64% male (Int); 61% male (control)	CIED	Automatic	Passive	Not stated	Condition-specific	In RPM group, 39 patients (13.4%) had CV-related hospitalisations vs. 42 patients (13.8%) in control group (NS); Mean LOS was 10 ± 14 days in the RPM vs. 11 ± 13 days in the control group (NS).	No significant difference
Amir, 2017 (Israel)	Cohort	Heart failure	Varied - <12	50	73.8 ± 10.3	62% male	Dedicated RPM unit + peripheral devices	Automatic	Passive	Not stated	Condition-specific	The HR for hospital readmission rates between the pre-RPM period and the RPM period was 0.07 (95% CI 0.01–0.54, P = 0.01).	Decreased
Bingler, 2018 (USA)	RCT	Heart disease - infants	Few months	31	1.44 (0.80 to 2.13) (1 month group); 0.70 (0.47 to 1.43) (2 month group)	56.2% female (1 month grp); 26.7% female (2 month group)	Tablet	Manual	Both	Not stated	Not specified	Higher risk of having a high resource ultilisation admission in control than RPM group (RR = 2.19, 95% CI 1.16-4.12, P = 0.016); Total LOS per 100 interstage days was significantly lower with RPM vs usual care. Difference in admissions NS - RPM 26 (0.9) vs. control 19 (1.0) - P = 0.75; Total ED presentations (ED presentations per 100 interstage days) RPM 20 (0.7) vs. control 13 (0.7) (P = 0.96).	Decreased
Bohingamu Mudiyansela ge, 2019 (Australia)	RCT	COPD and/or Diabetes	12	86 intervention; 85 control	70.7 ± 11.56 (Int); 70.13 ± 13.26 (control)	60% male (Int); 47% male (control)	Tablet + peripheral devices	Manual	Both (out of hours alerts)	VC	Not specified	Lower mean acute hospital LOS over 12 months in RPM (4.6 vs. 8.7 days; 95% CI: -8.6 to -0.4); Difference in hospitalisations NS (proportion of participants who had at least one hospitalisation 53% vs. control 55%, P = 0.813).	Decreased LOS, no significant difference in hospitalisations
Böhm, 2016 (Germany)	RCT	Patients with CIEDs (HF)	~24	175 intervention; 167 control	66.1 ± 10.1 (Int); 66.4 ± 10.7 (control)	77.2% male (Int); 82.3% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific (condition-specific result reported)	The number of HF hospitalisations per patient per year 0.24 for the RPM group and 0.30 for the control (P = 0.20).	No significant difference
Boriani, 2017 (Various - Europe and Israel)	RCT	Patients with CIEDs (HF)	~24	437 intervention; 428 control	66 ± 11 (Int); 67 ± 10 (control)	78.8% male (Int); 73.1% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	ED presentations (not followed by hospitalisation) significantly lower in RPM (IRR = 0.72, 95% CI 0.53–0.98, P = 0.04); Burden of CV-related healthcare resource utilization was 38% lower in RPM vs. control (IRR = 0.62, 95% CI 0.58–0.66, P<0.001); All-cause hospitalisation rates, estimated as the 2-year rate per 100 patients, were 96 (95% CI 86–106) and 90 (95% CI 80–100, P = 0.83), respectively. CV-related hospitalisations were 197 (111 due to HF) and 200 (103 due to HF) in RPM and control, respectively.	Decreased ED but increased unscheduled visits
Buchta, 2017 (Poland)	Cohort	Patients with CIEDs (unspecified)	24	287 intervention; 287 control	61.94 (53.25 – 70.75) (Int); 62.80 (56.04 – 69.51) (control)	84% male (both)	CIED	Automatic	Passive	Not stated	All-cause	No reduction in the number of defined medical contacts. Hospitalisations (P=NS) in control vs. RPM, respectively, in year 1, 2, 3 hospitalisations Year 1= 1.4 vs. 1.16; Year 2 = 0.74 vs. 0.42; Year 3= 0.55 vs. 0.36.	No significant difference
Bulava, 2016 (Czech Republic)	RCT	Patients with CIEDs (unspecified)	26	97 intervention; 101 control	66 ± 11 (Int); 68 ± 12 (control)	83.5% male (Int); 78.2% male (control)	CIED + dedicated RPM unit	Automatic	Passive	Telephone	Not specified	LOS shorter in RPM group (10.3 ± 8.1 days, median: 8.0 days) vs. control group (17.5 ± 19.9 days, with median of 10.5 days, P = 0.027); 213 hospitalisations in total: 124 (58.2%) in control group and 89 (41.8%) in RPM group (P = 0.127).	Decreased

Capucci, 2017 (Italy)	Cohort	Patients with CIEDs (HF)	12	499 intervention; 488 control	66 (12) (Int); 65 (13) (control)	77% male (both)	CIED	Automatic	Passive	Not stated	Not specified	Rate of hospitalisations in first 12 months of follow-up was 0.16 and 0.27/year in RPM and control group, respectively (RR = 0.59; P = 0.004).	Decreased
Celler, 2018 (Australia)	Cohort	Chronic conditions (unspecified)	9	114 intervention; 173 control	71.1 (9.3) (Int); 71.9 (9.4) (control)	64% male (Int); 56% male (control)	Dedicated RPM unit	Manual	NS	Not stated (But said reminded to record vitals)	Not specified	RPM patients significant (P = 0.006) reduction in rate of hospitalisations vs. controls (P = 0.869); After one year of RPM average expected LOS reduced by almost 68% from predicted value of 24.6 to 7.9 days.	Decreased
Chatwin, 2016 (UK)	RCT	Chronic lung disease (COPD and chronic resp failure)	6	38 intervention; 34 control	61.8 (11.9)	48% male	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	Respiratory hospitalisations for acute exacerbations at 6 months increased in RPM group — frequency 0.32 control vs. 0.63 RPM (mean difference 0.32, P = 0.026). Although time to first admission did not change, actual hospitalisations doubled from 18 to 36.	Increased
Clarke, 2018 (UK)	Cohort	COPD	3 monitor, 12 pre data	227	70.9 ± 8.9	50% male	Dedicated RPM unit + peripheral devices	Manual	Active	RM unit message	All-cause and condition-specific	Average LOS decreased in one group from 11.5 in period 12 months before to 6.5 days during RPM; In other group average LOS decreased 7.5 to 5.2 days; For all other causes there was a reduction in LOS during RPM period vs. period 12 months before (9%) but an increase (10%) vs. period immediately before RPM; COPD hospitalisations increased from 64 to 71; Other hospitalisations decreased 43 to 39.	Decreased LOS, variability in hospitalisations, and changed if compared to immediate pre or 12 months pre.
Comin-Colet, 2016 (Spain)	RCT	Heart failure	6	81 intervention; 97 control	74 ± 11 (Int); 75 ± 11 (control)	43% female (Int); 39% female (control)	Tablet	Manual	Active	Telephone, VC	All-cause and condition-specific	HF readmission (HR = 0.39, CI 0.19–0.77, P = 0.007) and CV readmission (HR = 0.43, CI 0.23–0.80, P = 0.008) were reduced in RPM group; mean LOS significantly reduced in RPM group for all cause, HF and CV readmissions. In patients hospitalised, mean LOS tended to be shorter in RPM group. In adjusted models, results were similar.	Decreased
Cross, 2019 (USA)	RCT	Inflammatory bowel disease	12	231 intervention; 117 control	40.1 ± 13.2 (Every other week [EOW] cohort; 36.4 ± 11.5 (Weekly cohort); 40.1 ± 11.7 (control). All = 38.9 ± 12.3 yrs)	41.7% male (Int every two weeks); 43.1% male (Int weekly); 45.3% male (control); All = 56.6% female	Smartphone	Manual	Passive	SMS	All-cause and condition-specific	IBD-related hospitalisations increased in the control group from 14.7 to 16.4; however in the RPM EOW and RPM Weekly, IBD-related hospitalisations decreased from 24.3 to 14.4 and 24.1 to 9.8 respectively. The difference in IBD-related hospitalisation was significant for the RPM weekly group only (P = 0.04); Non-IBD related hospitalisations increased from 3.4 to 11.2 in controls and decreased from 5.5 to 0.9 and 5.4 to 2.7 in the RPM EOW and weekly cohorts respectively (P = 0.02 in RPM EOW and p = 0.04 in RPM weekly; Decrease in hospitalisations but increase in non-invasive diagnostic tests, telephone calls and electronic encounters.	Decreased
D'Ancona, 2017 (Germany)	Cohort	Patients with CIEDs (unspecified)	12	720 RM capable devices (91 activated); 503 control	68 (58-75) (Int); 67 (57-75) (control)	20% female (Int); 21.5% female (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM patients had higher re-hospitalisation rate (45.2% vs. 34.8%, P = 0.059).	Increased
Davis, 2015 (USA)	Cohort	HF, COPD	3	117 intervention; 233 control	COPD: 61 (11) (Int); 63 (15.8) (control) HF: 62 (16.6) (Int); 65 (14.6) (control)	COPD: 62.1% female (Int); 60.3% female (control) HF: 45.8% female (Int); 56% female (control)	Dedicated RPM unit	Manual	Passive	Telephone, Dedicated RM unit message	All-cause	30-day re-admissions were reduced 50% for both chronic disease cohorts vs. control (COPD, 10.3% vs. 21.8%, HF, 8.5% vs. 17%); 37% reduction in ED presentations in the 30-day postdischarge period for COPD cohort compared with control patients (6.9% vs. 10.9%), but 75% increase in ED presentations for the HF cohort (11.9% vs. 6.8%) in the 30 days after the index discharge; Admissions 150 to 49 in COPD but 50 to 52 in HF.	Decreased for COPD, increased ED and hospitalisations for HF
De Luca, 2016 (Italy)	RCT	Nursing home patients; Mental health	Not specified	32 intervention; 27 control	77 (71-80) (Int); 85 (79-89) (control)	34.4% male (Int); 29.6% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	VC	Not specified	Admission to health care service was higher (x^2 = 3.96, P<0.05) in control group (8/27) vs. RPM group (3/32).	Decreased
De Simone, 2015 (Italy)	Non-randomised controlled trial/Quasi-experimental	Patients with CIEDs (unspecified)	24	499 intervention; 488 control	66 ± 12 (Int); 66 ± 13 (control)	76% male (Int); 78% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	RPM reduced risk of all-cause hospitalisations (87 vs. 129; 0.15 vs. 0.28 events/ year; IRR = 0.54, 95% CI 0.41–0.71, P < 0.001) and CV hospitalisations (60 vs. 89; 0.11 vs. 0.20 events/year; IRR = 0.54, 95% CI 0.38–0.75, P < 0.001) vs. control group; LOS was 517 days (0.91 days/year) in RPM group and 974 days (2.15 days/year) in control group.	Decreased
De Simone, 2019 (Italy)	Cohort	Patients with CIEDs (AF)	12	26 intervention; 45 control	82 [79–87] (Int); 85 [78–89] (control)	34.6% female (Int); 53.3% female (control)	CIED	Automatic	Passive	Not stated	All-cause	All-cause hospitalisations were 33, with lower event rate in RPM group vs. control (5.8; 95% CI 3.3–9.4 vs. 9.7; 95% CI 6.5–13.9 per 100 patient-months; P = 0.027); RR with RPM was significant for all-cause hospitalisation (RR= 0.44, 95% CI 0.21–0.93).	Decreased

Esteban, 2016 (Spain)	Cohort	COPD	24	120 intervention; 78 control	71.34 (Int); 70.1 (control) ALL: 70.83	86.6% male (Int); 87.2% male (control); All: 86.8% male	Smartphone	Manual	Active	Telephone	Condition-specific	After 2 years, both cohorts showed reduction in rate of hospitalisations (P<0.001) but reduction was significantly higher in RPM group (1.14 vs. 2.33, P<0.001); Significant differences in rate of ED presentations (pre-post = 0.4 (0.1–0.6) P = 0.006), cumulative LOS, and rate of 30-day readmission during study period; In multivariate analysis, being in the RPM group was independently associated with lower rates of hospitalisations (IRR = 0.38, 95% CI 0.27–0.54, P<0.0001), ED presentation (IRR = 0.56, 95% CI 0.35–0.92, P<0.02), and 30-day readmission (IRR = 0.46, 95% CI 0.29–0.74, P<0.001), as well as cumulative LOS (IRR = 0.58, 95% CI 0.46–0.73, P<0.0001).	Decreased
Flaherty, 2017 (USA)	RCT	Schizophrenia	3	20 intervention; 25 control	49.9 ± 12.7 (Int); 51.2 ± 11.1 (control)	90% male (Int); 96% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Not specified	RPM group significantly less likely vs. control group to have at least one hospitalisation (5.0% vs. 32.0%, P<0.05). Also, RPM group had significantly lower average number of hospitalisations (0.10 ± 0.45 vs. 0.60 ± 1.19, Mann Whitney U=4.67, df=1, P<0.05). RPM group also had significantly lower mean LOS (0.70 ± 3.13 vs. 2.56 ± 6.11, Mann Whitney U,=4.59, df=1, P<0.05). No significant differences were found between groups in terms of numbers of psychiatric hospitalisations (0.65 ± 1.04 vs. 0.52 ± 0.77). Additionally, RPM and control groups did not differ on ED presentations (0.60 ± 1.23 vs. 0.92 ± 1.19).	Decreased hospitalisations, no significant difference on ED
Galinier, 2020 (France)	RCT	Heart failure	18	305 intervention; 327 control	70.0±12.4 (Int); 69.7±12.5 (Control)	73.4% male (Int); 71.0% male (control)	Electronic scales + Dedicated RPM unit	Manual	Passive	Telephone	All-cause and condition-specific	Mean±SD number of unplanned hospitalisations for HF was 0.59±1.26 for telemonitoring and 0.75±1.42 for SC (rate ratio 0.84, 95% CI 0.62–1.15; P =0.28); RPM associated with 21% RR reduction in first unplanned hospitalisation for HF [hazard ratio (HR) 0.79, 95% CI 0.62–0.99; P = 0.044); Mean±SD annualised cumulative number of days in hospital 36.3±54.4 (RPM) vs 34.1±47.0 (SC) P = 0.34. Among the secondary outcomes, telemonitoring reduced the relative risk of occurrence of first unplanned hospitalisation for HF by 21% after adjustment for known predictive factors. Median time to first HF hospitalisation was also numerically delayed by 18 days in the telemonitoring group, but the difference did not reach the level of statistical significance.	No significant difference
Geller, 2019 (Germany)	RCT	Patients with CIEDs (HF)	12	333 intervention; 331 control	ICD 65 [58–70]; CRT-D 68 [62–74]; (control not reported)	ICD 85.0% male; CRT-D 77.7% male; (control group not reported)	CIED	Automatic	Passive	Not stated	All-cause	Hospitalisations for worsening HF in RPM vs. control group was 14 vs. 13 (ICD) and 30 vs. 34 (CRT-D). Number of affected patients was 10 vs. 8 (ICD: 7.0% vs. 6.1%, P = 0.81) and 17 vs. 26 (CRT-D: 8.9% vs. 13.0%; P = 0.26), the median length of hospital stay was 9.0 vs. 7.0 days (ICD: P = 0.38) and 7.0 vs. 7.5 days (CRT-D: P = 0.43), respectively.	No significant difference
Gingele, 2019 (Netherlands)	RCT	Heart failure	12	197 intervention; 185 control	71.0 ± 11.9 (Int); 71.9 ± 10.5 (control)	58% male (Int); 60% male (control)	Dedicated RPM unit	Manual	Active	"contacted with advice" "twice had personal contact with specialist"	Condition-specific	RPM group had significantly fewer HF-related hospitalisations vs. control group (IRR = 0.54, 95% CI 0.31–0.88). However, HF-related LOS was not significantly shorter in RPM group (IRR = 0.60, 95% CI 0.33–1.07).	Decreased hospitalisations, no significant diference in LOS
Hale, 2016 (USA)	RCT	Heart failure	3	11 intervention; 14 control	68.4 (11.8) (intervention); 74.4 (10.4) (control)	64% male (both)	MedSentry electronic medication device	Automatic	Active	Telephone	All-cause and condition-specific	Approximately 9% (1/11) of RPM participants were hospitalised one or more times vs. 50% (7/14) control participants (P = 0.04), a relative risk reduction in hospitalisation of approximately 82%. RPM group had significantly fewer all-cause hospitalisation days vs. controls (4 vs 34, P = 0.03) and there was a reduction in the LOS for HF-related and non-HF-related hospitalisations (NS, P = 0.24). ED presentations all cause and HF-related were reduced (NS, 6 to 3 and 3 to 1, respectively).	Decreased
Hansen, 2018 (Germany)	RCT	Patients with CIEDs (HF)	13	102 intervention; 108 control	62.5 ± 12.2 (Telemetry); 64.7 ± 9.1 (remote + phone); 65.4 ± 11.1 (visit)	16.7% female (telemetry); 13.2% female (remote + phone); 16.4% female (visit)	CIED + dedicated RPM unit	Automatic	Passive	Website	Condition-specific	HF-hospitalisation occurred at similar rates in the RPM and control groups (9.8% vs. 12.0%, P = 0.605).	No significant difference
Heidbuchel, 2015 (Various - Europe)	RCT	Patients with CIEDs (unspecified)	24	159 intervention; 144 control	62.4 ± 13.1 (ALL); 62.0 ± 13.9 (Int); 62.9 ± 12.3 (control)	80.5% male (ALL); 78% male (Int); 83.3% male (control)	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	Fewer CV hospitalisations and shorter LOS in RPM patients, but NS. CV hospitalisations control vs. RPM = 0.85 (1.43) vs. 0.67 (1.18), P= 0.233; LOS (days) 8.26 (18.6) vs. 6.31 (15.5), P= 0.266.	No significant difference

Ho, 2016 (Taiwan)	RCT	COPD	6	53 intervention; 53 control	81.4 ± 7.8 (Int); 79.0 ± 9.6 (control)	81% male (Int); 72% male (control)	Website	Manual	Active	Not stated	All-cause and condition-specific	RPM associated with a significant reduction in number of all-cause re-admissions from 0.68 to 0.23 per patient (P = 0.002). RPM patients had fewer ED presentations for all causes vs. control group (0.36 vs. 0.91 per patient, P = 0.006).	Decreased
Ishani, 2016 (USA)	RCT	CKD	12	451 intervention; 150 control	75.3 ± 8.1 (Int); 74.3 ± 8.1 (control)	98.7% male (Int); 98.0% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	VC	All-cause	RPM did not reduce the risk for hospitalisation or ED presentations vs. usual care; Hospitalisations HR = 1.15; 95% CI 0.80-1.63, ED presentations HR = 0.92; 95% CI, 0.68-1.24.	No significant difference
Jenneve, 2020 (France)	Cohort	Heart failure	24	159	72.9 years (34–96)	64.3% male	Website + scale	Manual	Passive	Telephone	Condition-specific	Mean number of days hospitalised for HF per patient per year was 8.33 (6.84–10.13) in the year preceding enrollment, 2.6 (1.51–4.47) at one year of follow-up, and 2.82 at two years of follow-up (1.30–6.11) ($p < 0.01$ for both comparisons). Number of patients hospitalised for HF was 112 in the year preceding enrollment and 23 or 15 at 1 and 2 years of follow up, respectively.	Decreased
Jimenez-Marrero, 2020 (Spain)	RCT	Heart failure	6	50 intervention; 66 control	77 years	47% female	Tablet computer	Manual	Passive	Not stated	All-cause and condition-specific	There were statistically significant lower risks hospitalisations comparing telemedicine to usual care; Hospitalisation from non-cardiovascular causes was similar in the two arms- Usual care vs Telemedicine - HF hospitalisation 29 vs 10 P = 0.011 HR 0.38 (0.16–0.90); CV hospitalisation 37 vs 13 P = 0.009 HR 0.40 (0.19–0.86); Non-CV hospitalisation 12 vs 7 P= 0.796 HR 1.01 (0.35–2.88); All-cause hospitalisation 51 vs 21 P = 0.017 HR 0.52 (0.28–0.98)	Decreased
Kalter-Leibovici, 2017 (Israel)	RCT	Heart failure	30	682 intervention; 678 control	70.8 (11.6) (Int); 70.7 (11.0) (control)	69.3% male (Int); 75.7% male (control)	Dedicated RPM unit	Manual	Passive	Telephone, VC	All-cause	No significant differences in LOS (adjusted RR = 0.886; 95% CI 0.749-1.048), and hospitalisations for all causes (adjusted RR = 0.935; 95% CI 0.840-1.040).	No significant difference
Kao, 2016 (USA)	Cohort	Heart failure	36	623 intervention; 623 control	78.76 ± 9.08 (Int); 77.39 ± 8.59 (control)	56.7% male (Int); 52.3% male (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	A reduction of 22.7% in quarterly hospitalisations noted in RPM vs. matched controls (D = -0.05 hospitalisations/quarter; 95% CI -0.09 to -0.01; P = 0.012). No significant differences between RPM and matched control cohorts in all-cause LOS per quarter or all-cause ED presentations.	No significant difference in LOS or ED, decreased hospitalisations
Kenealy, 2015 (New Zealand)	RCT - except site C	Chronic conditions (unspecified)	6	98 intervention; 73 control	SITE A: 72 (62–83) (Int); 72 (60–77) (control) SITE B: 67 (64–74) (Int); 67.5 (63– 72.5) (control) SITE C: 57 (53-60) (Int); no control group	SITE A: 39% female (Int); 29% female (control); SITE B: 38% female (both); SITE C: 60% female (no control group)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause	RPM group showed no significant change in hospitalisations vs. usual care (coefficient 0.32, P = 0.15), ED presentations (coefficient -0.08, P = 0.91), or LOS (coefficient 0.51, P = 0.09).	No significant difference
Kessler, 2018 (Various - Europe (France, Germany, Italy, Spain)	RCT	COPD	12	172 intervention; 173 control	67.3 ± 8.9 (Int); 66.6 ± 9.6 (control); ALL 66.9 ± 9.3	69.4% male (Int); 69.8% male (control)	Telephone	Manual	Active	Telephone	All-cause and condition-specific	No significant difference in all-cause LOS (non-parametric analysis (p=0.161) or ANOVA comparison of the mean values adjusted for country differences (−5.3 days, 95% CI −13.7 to 3.1; P = 0.212). Difference was 7.4 ± 35.4 in RPM group and 22.6 ± 41.8 in control group, with medians (IQR) of 0 (0−203) days and 5 (0 −259) days, respectively. The total numbers of unplanned hospitalisations were similar for both groups (RPM group, n=157; control group, n=160). LOS due to acute exacerbation of COPD not significantly different.	No significant difference
Koehler, 2018 (Germany)	RCT	Heart failure	12	765 intervention; 773 control	70 (11) (Int); 70 (10) (control)	70% male (Int); 69% male (control)	Tablet + peripheral devices	Manual	Active	Telephone	Condition-specific	RPM group had shorter LOS vs. control group for unplanned hospitalisations due to worsening HF (mean 3.8 days per year, 95% CI 3.5–4.1 vs. 5.6 days per year, 5·2–6·0, respectively). The percentage of days lost for this outcome for RPM and control groups was 1.04% (95% CI 0.96–1.11) and 1.53% (1.43–1.64), respectively (ratio 0.80, 95% CI 0.67–0.95; P = 0.0070).	Decreased

Koulaouzidis, 2019 (UK)	Cohort	Heart failure	12	124 intervention; 345 control	68.1 (12.7) (Int); 67.5 (10.6) (control)	78.2 male (Int); 68.1% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause hospitalisation and condition-specific readmission	There was no difference between the two groups in all-cause hospitalisation, either in number of subjects hospitalised (P = 0.7) or in number of admissions per patient P = 0.6), No difference in number of HF-related readmissions per person between the two groups (P = 0.5), but LOS per person was higher in control group (P = 0.03).	Decreased LOS, no significant difference in hospitalisation
Kraai, 2016 (Netherlands)	RCT	Heart failure	9	94 intervention; 83 control	69 ± 12 (Int); 69 ± 11 (control);	70% male (Int); 75% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition-specific	HF-readmission 28% vs. 27% P = 0.87; All-cause readmission was 49% vs. 51% (P = 0.78).	No significant difference
Kurek, 2017 (Poland)	Cohort	Patients with CIEDs (HF)	12	287 intervention; 287 control	63 (56–69) (Int); 62 (53–70) (control)	84% male (both)	CIED + dedicated RPM unit	Automatic	Passive	Not stated	Condition-specific	Number of HF-related hospitalisations in 1-year observation was comparable (1.71 vs. 1.65 visits/per patient, P = 0.27).	No significant difference
Ladapo, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	24	2849 intervention (ICD, CRT-D and pacemaker); 2849 matched control	After matching ICD: 64 (12) (Int); 65 (12) (control); CRT-D: 69 (10) (both); pacemaker: 74 (11) (both)	After matching, ICD: 79% male (both); CRT-D: 73% male (both); Pacemaker: 55% male (both)	CIED	Automatic	Passive	Not stated	Not specified	RPM patients less likely to have ED presentations (P = 0.050) and had fewer hospital stays (P = 0.057). RPM patients did not significantly differ from control in ED presentations or hospital care. RPM patients over a 24-month period similar or less frequent utilization of emergency and hospital care, compared with those followed in the office (reductions in utilization most pronounced among ICDs).	Decreased
Lanssens, 2017 (Belgium)	Cohort	Gestational hypertensive disorders	12	48 intervention; 98 control	31.69 (4.25) (Int); 31.94 (4.77) (control)	100% female (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated ("Contacting patients at home" but did not specify how)	Not specified	Prenatal hospitalisations and hospitalisations until delivery were lower in RPM vs. control when a univariate analysis was performed - 56.25% (27/48) vs.74.49% (73/98) and 27.08% (13/48) vs. 62.24% (61/97). This was not significant in multivariate analysis.	No significant difference in multivariate analysis, decreased in univariate analysis.
Lanssens, 2018 (Belgium)	Cohort	Gestational hypertensive disorders	12	90 intervention; 320 control	30.97 (±5.61) (Int); 30.53 (±5.17) (control)	100% female (maternal prenatal study)	Peripheral devices	Manual	Passive	Not stated ("Contacting patients at home" but did not specify how)	Not specified	In both uni- and multivariate analyses, RPM group had, vs. control group, less prenatal admission (51.62% vs. 71.63%), and less prenatal admissions until the moment of the delivery (31.40% vs. 57.67%).	Decreased
Leng Chow, 2020 (Singapore)	Non-randomised controlled trial (Quasi-experimental)	Heart failure	12	150 intervention; 55 control	57.9 (Int); 63.9 (control)	60.7% male (Int); 58.2% males (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	All-cause and condition-specific	After adjusting for differences in age and years of HF diagnosis, average HF-related bed days per patient at 180 days (TM=1.2, STS=6.0 days; p<0.01) and at one year (TM=2.2, STS=6.6 days; p=0.02), remained significantly lower for TM compared with STS. Allcause bed days per patient at 180 days were also significantly lower for TM compared with STS (TM=5.0, STS=9.8 days; p=0.03); TM was associated with reduced all-cause 180-day readmission by 38% (HR 0.62 (0.38–1.00); p=0.05)	Decreased
Lew, 2018 (USA)	Non-randomised controlled trial	Peritoneal dialysis patients	Not specified	269	56 (43.6–64.3)	56.9% male	Peripheral devices	Manual	Active	VC	Not specified	Use of RPM collected weight associated with fewer hospitalisations (adjusted OR= 0.54, 95% CI 0.33–0.89) and shorter LOS (adjusted OR = 0.46, 95% CI 0.26–0.81). Use of RPM collected BP associated with longer LOS (adjusted OR = 1.95, 95% CI 1.10–3.46) and increased odds of hospitalisation (adjusted OR 1.65, 95% CI 1.02–2.65).	Decreased (when monitoring weight), increased (when monitoring BP).
López-Liria, 2020 (Spain)	Non-randomised controlled trial (Quasi-experimental)	Patients with CIEDs (unspecified)	60	21 intervention; 34 control	81 ± 7 (Int); 8 ± 6 (control)	31% women	CIED	Automatic	Passive	Not stated	All-cause and condition-specific	Hospitalisations were 19 (90.48) in RM vs 33 (97.06) in control P = 0.323	No significant difference
Lu¨thje, 2015 (Germany)	RCT	Patients with CIEDs (unspecified)	15	73 intervention; 82 control	66.0 (± 12.0) (Int); 65.9 (± 12.1) (control)	80.5% male (Int); 74.2% male (control)	CIED	Automatic	Passive	Telephone	Condition-specific	The mean number of ED presentations was not significantly different between the two groups (RPM group 0.10 + 0.25 vs. control group 0.10 + 0.23; P = 0.7295). 20 RPM patients and 22 control patients were hospitalised for worsened HF (no significance test stated).	No significant difference

Lyth, 2019 (Sweden)	Cohort	HF, COPD	12	94	HF: 84 (65–100) COPD: 74 (65–86)	HF: 50% female COPD: 61.1% female	Digital pen and Health Diary System	Manual	Active	SMS	Condition-specific	Hospitalisations was 0.94 for HF and 1.16 for COPD. This was significantly lower than expected, with 67% in the HF group (P<0.001) and 61% in the COPD group (P = 0.003). Mean values for inpatient care and emergency care in HF and COPD significantly lower in observed vs. expected (P<0.001).	Decreased
Martin-Lesende, 2017 (Spain)	Cohort	HF, COPD or other chronic lung disease	12	28	78.9 (7.5)	45.3% male	Smartphone	Manual	Passive	SMS	All-cause and condition-specific	Significant reduction in hospitalisations, from 2.6 admissions/patient in the previous year (SD: 1.6) to 1.1 (SD: 1.5) during the one year RPM follow-up (P<0.001), and ED presentations, from 4.2 (SD: 2.6) to 2.1 (SD: 2.6) (P<0.001) was observed. The LOS was reduced non-significantly from 11.4 to 7.9 days.	Decreased hospitalisations and ED, no significant difference in LOS
McDowell, 2015 (UK)	RCT	COPD	6	48 intervention; 52 control	69.8 (7.1) (Int); 70.2 (7.4) (control)	58.2% female (Int); 54.5% female (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated - ("Contacted patient" but did not specify how)	Not specified	At 6 months there was a higher number of ED presentations, hospitalisations and longer LOS in control group vs. RPM group, but differences were NS (P = 0.40, P = 0.42, P = 0.59 respectively).	No significant difference
McElroy, 2016 (USA)	Cohort	Patients post surgery (cardiac)	1	27 intervention; 416 control	62.9 (9.8) (intervention); 65.9 (14.1) (control)	85.2% male (intervention); 65.9% male (control)	Tablet + peripheral devices	Manual	Active	Telephone, VC	Not specified	Readmission rate for the RPM and control groups were similar (7.4% vs. 9.9%, P = 0.65). LOS 9.1 ± 9.0 vs. RPM 8.7 ± 3.6 P = 0.65.	No significant difference
Milan Manani, 2020 (Italy)	Case-control	Peritoneal dialysis patients	6	35 intervention; 38 control	62.8 (44.7–77.1) (Int); 57.9 (50.0–73.1) (control)	77% male (intervention); 71% male (control)	NS	Both	NS	Not stated	All-cause and condition-specific	Decreased disease-specific hospitalizations (RPM 18.2% versus control 77.8%) (p = 0.022); 4 reasons for ED visits and significantly decreased two: Overhydration, mean ± SD RPM 0.17 ± 0.45bs control 0.66 ± 1.36 P = 0.0421; Exit site infections, mean ± SD RPM 0.17 ± 0.56 vs 0.42 ± 0.85 P = 0.0451.	Decreased
Mirón Rubio, 2018 (Spain)	Cohort	COPD	6	26	78 (7.9)	93% male	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone, In-person	Not specified	The number of ED presentations decreased by 38%, from 53 visits during control period (in 26 (92.9%) patients; mean 1.89 visits/patient; range 0–6) to 33 visits during RPM period (in 15 (53.6%) patients; mean 1.18 visits/patient; range 0–6, p = 0.03). Fewer hospitalisations or ED presentations during RPM period: only 15 patients (53.6%) vs. 26 (92.8%) patients during control period (RR = 0.58; CI 95% 0.40 – 0.83, P =0.002).	Decreased
Mizukawa, 2019 (Japan)	RCT	Heart failure	24	15 (Int); 15 (control)	70.5 ± 13.3 (Int); 74.5 ± 12.1 (control)	50% male (intervention); 52.6% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Not stated	All-cause and condition-specific	Rates of readmission for HF were significantly different (P = 0.048), with significant improvement in the CM group, as compared with the UC group (P = 0.020). The hazard ratio for HF readmissions in the CM group versus the UC group was 0.29 (95% CI, 0.09 to 0.92; P = 0.035)	Decreased
Nancarrow, 2016 (Australia)	Cohort	Geriatric	12	200	74.8 ± (8.2)	41.5% male	Tablet + peripheral devices	Manual	Active	VC	Not specified	Self-reported health service use showed decline in ED presentations (X^2= 14.950, n = 122; 6 df, P = 0.021); hospitalisation (non-local) (x^2 61.44, n = 118, 12 df, P< 0.001). However, there was no significant difference in hospitalisation in the local hospital (c^2 21.190, n = 122; 16 df, P = 0.171).	Decreased ED, no significant difference local hospitalisations
Nouryan, 2019 (USA)	RCT	Heart failure	6	42 intervention; 47 control	81.4 (Int); 84.9 (control)	32% male	Dedicated RPM unit + peripheral devices	Manual	Active	VC, Feedback reports to patient as well	All-cause and condition-specific	38% of RPM patients had ≥1 ED presentation vs. 60% of control (P = 0.04), while 48% of RPM had ≥1 hospitalisation vs. 55% of control (P = 0.47). LOS (days) was 4.0 for RPM vs. 7.4 for control (P = 0.39).	Decreased ED, hospitalisation and LOS not significantly different
Nunes-Ferreira, 2020 (Portugal)	Quasi-experimental	Heart failure	12	25 intervention; 50 control	65.4 ± 9.7 (Int); 64.58 ± 13.73 (control)	32% female (Int); 38% female (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Not stated	All-cause and condition-specific	RPM significantly reduced HF-related hospitalisation rate (12% vs. 36%, HR 0.29; 95% CI 0.10–0.89; P < 0.05) and all-cause hospitalisations (HR 0.29; 95% CI 0.11–0.75; P < 0.001); Patients in the TM group lost an average of 5.6 days per year compared with 48.8 days in the UC group.	Decreased
Olivari, 2018 (Italy)	RCT	Heart failure	12	229 intervention; 110 control	79.6 ± 6.8 (Int); 80.9 ± 7.3 (control)	61.1% male (Int); 65.4% male (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Not stated	All-cause	In the RPM and control group respectively, mean LOS of 13.1 ± 16.3 and 16.5 ± 32.0 (P = 0.21) days. Hospitalisations for HF occurred in 161 and 93, with a mean LOS of 13.5 ± 14.2 and 19.0 ± 39.3 (P = 0.20) days, in the RPM and control group, respectively.	No significant difference
Ong, 2016 (USA)	RCT	Heart failure	6	715 intervention; 722 control	73 (62-84) (Int); 74 (63-82) (control)	46.6% (42.9-50.2) female (Int); 47.1% female (42.8-51.4) (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	All-cause	The RPM and control groups did not differ significantly in readmissions for any cause 180 days after discharge, which occurred in 50.8% (363 of 715) and 49.2% (355 of 722) of patients, respectively (adjusted HR = 1.03; 95% CI 0.88-1.20; P = 0.74).	No significant difference
Orozco-Beltran, 2017 (Spain)	Quasi-experimental	Chronic conditions (unspecified)	12	521	70.4 (10.3)	38.9% female	Tablet	Manual	Passive	Telephone, VC	All-cause and condition-specific	Decrease in ED presentations (98, 18.8% vs. 67, 12.8%; P<.001). Fewer hospitalisations due to an emergency (105, 20.2% vs. 71, 13.6%; P<.001) or disease exacerbation (55, 10.5% vs. 42, 8.1%; P<.001).	Decreased

Pedone, 2015 (Italy)	RCT	Heart failure	6	50 intervention; 46 control	79.9 ± 6.8 (Int); 79.7 ± 7.8 (control)	46.8% male (Int); 30.2% male (control)	Smartphone + peripheral devices	Manual	Active	Telephone	All-cause	Hospitalisations during the 6 months of follow-up: 20 in control group (incidence rate 129/100 person-years, 95% CI = 84–200) and 8 (incidence rate 39/100 person-years, 95% CI = 20–77) in RPM group (IRR = 0.30, 95% CI 0.12–0.67).	Decreased
Pekmezaris, 2019 (USA)	RCT	Heart failure	3	46 intervention; 58 control	58.4 (15.2, 19–93) (Int); 61.1 (15.0, 26–90) (control)	43% female (Int); 40% female (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone, VC	All-cause and condition-specific	Groups did not differ regarding binary ED presentations (RR = 1.37, CI 0.83–2.27), hospitalization (RR = 0.92, CI 0.57–1.48), or length of stay in days (RPM = 0.54 vs. control =0.91). Number of all-cause hospitalisations was significantly lower for control (RPM= 0.78 vs. control = 0.55; P = 0.03).	No significant difference in binary ED, hospitalisation, or LOS, increased for all-cause hospitalisation
Persson, 2019 (Sweden)	Cohort	HF, COPD	12	53	HF - 83±7 (65–100); COPD - 75±6 (65–86)	54.2% female	Digital pen and Health Diary System	Manual	Passive	Not stated	All-cause	Compared to adjusted hospitalization rates prior inclusion, the intervention significantly reduced hospitalization rates for both groups	Decreased
Piccini, 2016 (USA)	Cohort	Patients with CIEDs (unspecified)	19	34,259 intervention; 58,307 control	69.7 ± 12.7 (Int); 72.6 ± 13.1 (control)	66.1% male (Int); 60.9% male (control)	CIED	Automatic	Passive	Not stated	All-cause	RPM had lower adjusted risk of all-cause hospitalisation (adjusted HR = 0.82; 95% CI 0.80–0.84; P = 0.001) and shorter mean LOS (5.3 days vs. 8.1 days, P < 0.001).	Decreased
Ricci, 2017 (Italy)	Quasi-experimental	Patients with CIEDs (unspecified)	12	102 intervention; 107 control	69.69 ± 10.17 (Int); 68.89 ± 11.46 (control)	84.31% male (Int); 85.98% (control)	CIED + transmitter	Automatic	Passive	Dedicated RM unit message	Condition-specific	More CV-related hospitalisations in control vs. RPM patients (SC: 22 (24.72%) vs. RPM: 7 (8.14%); P = 0.0032); more ED presentations (control: 5 (5.62%) vs. RPM: 0 (0.00%); P = .059); Regarding CV hospitalisations, there was no statistically significant difference in LOS between patients with RPM and control patients (6.6 ± 4.7 days [44 hospitalizations] vs. 6.4 ± 4.8 days [14 hospitalizations], P = 0.8990).	Decreased ED and hospitalisations, no significant difference in LOS
Riley, 2015 (USA)	Cohort	Heart failure	6	45 intervention; 45 control	Of those matched 65.9 (14.7)	Of those matched 48.9% female	Smartphone + peripheral devices	Manual	Active	Not stated	Not specified	Matched cohort saw similar decrease pre/post as RPM saw pre/post. For comparing directly enrolled vs. matched at 30 days post - 0.47 (1.10) vs. 0.56 (0.87); 60 days 1.24 (3.24) vs. 0.87 (1.44); 182 days 1.87 (4.54) vs. 1.22 (1.71). For enrolled vs. matched, at 30 days, time F (1,88) = 43.87, p < 0.0001, time · group = 0.63, p = 0.429; at 90 days, time F (1,88) = 50.87, p < 0.0001, time · group = 0.12, p = 0.727; and at 182 days, time F (1,88) = 45.36, p < 0.0001, time · group = 1.00, p = 0.320.	No significant difference
Ringbæk, 2015 (Denmark)	RCT	COPD	6	141 intervention; 140 control	69.8 (9.0) (Int); 69.4 (10.1) (control)	61% female (Int); 45% female (control)	Tablet + peripheral devices	Manual	Active	VC	Condition-specific	No significant difference found in hospital admissions for COPD between the groups (P = 0.74).	No significant difference
Rosner, 2018 (USA)	Cohort	Patients post surgery (orthopaedic)	3	186 intervention; 372 control;	57.00 (7.32)	50% female	Website	Manual	Active	E-mail	Not specified	90 day hospitalisation rates in baseline and RPM groups were 3.0% (11 of 372) and 1.6% (3 of 186), respectively (RR = 0.545; CI 0.154 - 1.931, P = 0.40).	No significant difference
Sanabria, 2019 (Colombia)	Cohort	Peritoneal dialysis patients	12	360	57±17	44% female	Dedicated RPM unit	Manual	Both	Not stated	Not specified	RPM decreased hospitalization rate (0.36 fewer hospitalizations per patient-year; IRR 0.61 [95% CI 0.39 – 0.95]; p = 0.029) and hospitalization days (6.57 fewer days per patient-year; IRR 0.46 [95% CI 0.23 – 0.92]; p = 0.028).	Decreased
Sardu, 2016 (USA)	RCT	Patients with CIEDs (HF)	12	89 intervention; 94 control	71.8 ± 8.5 (Int); 72.6 ± 5.7 (control)	71.9 male (Int); 79.8% male (control)	CIED	Automatic	Active	Telephone, In-person	Condition-specific	There was a significant difference in hospitalisations (15.7 vs. 28.7, P = 0.02) comparing RPM patients to control group. At multivariate analysis, RPM was the only factor predicting HF hospitalisation (HR = 0.6, 95% CI 0.42–0.79, P = 0.002).	Decreased
Shany, 2017 (Australia)	RCT	COPD	12	11 intervention; 18 control	72.1 ± 7.5 (Int); 74.2 ± 9.0 (control)	48% male (Int); 43% male (control)	Dedicated RPM unit	Manual	Active	Telephone, In-person	Condition-specific	No statistically significant differences were demonstrated for the rate of ED presentations and hospitalisations. However, during the study, being in RPM group was associated with 20% relative reduction in the risk of admission and 14% relative reduction in the risk of ED presentation. Analysed as LOS per admission, there was no significant difference between the control and RPM patients.	No significant difference, though some relative reduction in risk
Sink, 2018 (USA)	RCT - except 17 non-randomised participants	COPD	8	83 intervention; 85 control	59.89 ± 1.09 (Int); 61.94 ± 1.07 (control)	34.9% male (Int); 37.6% male (control)	Smartphone	Manual	Passive	Not stated	Condition-specific	There were significantly fewer COPD-related hospitalisations in RPM group vs. control with 6 and 16, respectively. The absolute RR was 11.6% and the relative RR was 61.7%.	Decreased
Soriano, 2018 (Spain)	RCT	COPD	12	87 intervention; 82 control	71.5 ± 8.0 (Int); 71.3 ± 8.9 (control)	78.3% male (Int); 82.5% male (control)	Telephone	Manual	Passive	SMS	Condition-specific	Shorter mean LOS in RPM group (18.9 ± 16.1 days) compared to the control group (22.4 ± 19.5 days, P = 0.308). There were no statistically significant differences in primary efficacy analysis of the proportion of participants who had a severe exacerbation leading to a hospital admission or ED presentation over the 12-month period (60% in RPM vs. 53.5% in control, P = 0.321).	No significant difference

Srivastava, 2019 (USA)	Cohort	Heart failure	12	197 intervention; 870 control	73.4 (11.14) (Int); 75.4 (11.0) (control)	98.0% male (Int); 97.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Not specified	A significantly lower total admissions (1.1 vs. 1.6 admissions) and LOS (5.7 vs. 11.3 days) were seen in RPM group compared to the prior year (1.6 vs. 1.7, P<0.05; and 9.5 vs. 14 days, P<0.01, respectively). The RPM group also had a significantly lower LOS vs. control group (9.0 vs. 14.9, P<0.01). However, there was no significant difference in hospitalisations between the RPM group and control group (1.4 vs. 2.0, P<0.07). The number of ED presentations was not significantly different.	Decreased if looking pre-post, no significant difference compared to controls
Stamenova, 2020 (Canada)	RCT	COPD	6	41 intervention; 40 control	71.98 (9.52) (Int); 72.78 (9.16) (control)	44% female (Int); 48% female (control)	Dedicated RPM unit + peripheral devices	Manual	Passive	Telephone	All-cause and condition specific	No significant difference in number of ED visits and hospitalizations during the 6 months preceding enrollment and during their participation in the trial. For COPD-related hospital admissions, there was a decrease but not a statistically significant effect across the 3 groups (P=0.07). No effect for COPD-related ED visits.	No significant difference
Tajstra, 2020 (Poland)	RCT	Patients with CIEDs (HF)	12	299 intervention; 301 control	64.0 (13.0) (Int); 64.0 (12.0) (control)	81.6% male (Int); 80.7% male (control)	CIED + dedicated RPM unit	Automatic	Both	Not stated	Condition-specific	Hospitalization rate due to cardiovascular reasons was higher in control as compared to RPM (45.5% vs 37.1%, P = 0.045).	Decreased
Ten Eyck, 2019 (USA)	Cohort	Heart failure	12	Different levels of "engaged" interventions 8907; 8907 control	73.0 (9.92) (Int); 73.68 (10.6) (control)	46.3% male (Int - engaged); 47.5% male (control - non-engaged)	Tablet + peripheral devices	Manual	Active	Telephone	All-cause	Engaged members who used their Bluetooth-enabled scales an average of 25 or more days per month demonstrated significantly lower post-index acute IP medical service utilisation vs. control group members (P<0.0001). Conversely, engaged members who used their scales ≤ 9 days per month or 9.1 to 18 days per month had significantly higher post-index acute IP medical service utilisation vs. control group (P< 0.0001 and P = 0.008, respectively). Engaged members had a significantly shorter average LOS vs. non-engaged members (4.14 vs. 4.66 days; P< 0.0001).	Decreased
Thomason, 2015 (USA)	Cohort	Heart failure	3	80 intervention; 1276 control	83.75 (SD 8.61) (Int); 81.97 (SD 10.55) (control)	60% female (Int); 60.2% female (control)	Dedicated RPM unit	Manual	Active	Telephone	All-cause	Control group had a 21% all-cause hospital readmission rate vs. RPM group who had a 10% all-cause readmission rate.	Decreased
Trucco, 2019 (Italy)	Cohort	Home-ventilated neuromuscular patients	14	48 intervention; 48 control	16.4 (8.9–22.1) (Int); 15 (9.2–21.5) (control)	62.5% male (Int); 75.0% male (control)	Dedicated RPM unit + peripheral devices	Both	Passive	Telephone, VC	Condition-specific	Hospitalisations were significantly reduced post-RPM patients when compared to pre-RPM (11 vs. 24, P = 0.04) and to controls (11 vs. 21, P = 0.03). Median LOS was significantly lower in RPM patients vs. controls (6 vs. 7 days, P = 0.03). ED presentations were significantly reduced during the RPM trial (from 12 to 2, P<0.05) while hospital admissions were not significantly lower during RPM compared with pre-RPM (from 12 to 9 P>0.05).	Decreased hospitalisations, LOS, ED
Udsen, 2017 (Denmark)	Cluster RCT	COPD	12	578 intervention; 647 control	69.55 (9.36) (Int); 70.33 (9.11) (control)	48.27% male (Int); 43.74% male (control)	Tablet + peripheral devices	Manual	Active	Not stated	Condition-specific	Mean (SE) = Hospital admissions: RPM 2756.1 (463.8) vs. usual care 2753.1 (458.9); ED presentations 343.4 (24.8) vs. usual care 278.3 (21.5); Resource use is consistently higher in the RPM group.	Increased
van den Heuvel, 2020 (Netherlands)	Case-control	Gestational hypertensive disorders	9	103 intervention; 133 control	33.7 (4.6) (Int); 33.1 (4.7) (control)	100% female (maternal study)	Dedicated RPM unit + peripheral devices	Manual	Both	Not stated	Condition-specific	Observational admissions for hypertension or diagnosis/exclusion of suspected preeclampsia were significantly lower in RPM compared to the control group (2.9% vs 13.5% of participants, p = 0.004).	Decreased
Vianello, 2016 (Italy)	RCT	COPD	12	181 intervention; 81 control	75.96 (6.54) (Int); 76.48 (6.16) (control)	72.2% male (Int); 73.1% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone (only home visit for event management)	All-cause and condition-specific	The hospitalization rate for COPD and/or for any cause was not significantly different in the two groups (IRR = 0.89, 95% CI 0.79–1.04, P = 0.16 and IRR = 0.91, 95% CI 0.75 – 1.04); p = 0.16, respectively). The readmission rate for COPD and/or any cause was, however, significantly lower in the RPM group vs. control (IRR = 0.43, 95% CI 0.19–0.98, P = 0.01 and 0.46, 95% CI 0.24–0.89, P =0.01, respectively). LOS was not significantly different in the two groups.	No significant difference
Wagenaar, 2019 (Netherlands)	RCT	Heart failure	12	150 intervention; 150 control	66.6 ± 11.0 (Int); 66.9 ± 11.6 (control)	75.3% male (Int); 72.7% male (control)	Website	Manual	Passive	Telephone, Website	All-cause and condition-specific	No difference in hospitalisations (RPM vs. UC, 57 vs. 66, HR = 0.85, 95% CI 0.59–1.21).	No significant difference
Walker, 2018 (UK, Estonia, Sweden, Spain, Slovenia)	RCT	COPD	9	154 intervention; 158 control	71.0 (66.0, 75.8) (Int); 71.0 (65.3, 76.0) (control)	65.6% male (Int); 66.5% male (control)	Tablet + peripheral devices	Manual	Passive	Telephone	Not specified	The average LOS for all cause hospitalisations was 4.0 (IQR:1.0 - 9.0) days for control group and 1.0 (IQR:1.0 - 6.7) day for RPM group (P = 0.045). Compared to control, RPM patients who were hospitalised during the trial (n=41 and 45, respectively) were less than half as likely to be re-hospitalised (IRR = 0.46, P = 0.017). There was no difference between groups in the rate of hospitalisation (0.79 vs. 0.99, P = 0.276).	Decreased LOS, no significant difference in hospitalisation

Ware, 2020 (Canada)	Cohort	Heart failure	6	156	58.3 (15.5)	77.8% male	Smartphone + peripheral devices	Manual	Passive	Not stated	All-cause and condition-specific	HF-related hospitalizations decreased from 0.46 (0-4, 0.71) to 0.23 (0-3, 0.51); IRR 0.50 (P<.001). All-cause hospitalizations decreased from 0.64 (0-7, 0.89) to 0.49 (0-6, 0.97); IRR 0.76 (P=.02). LOS & ED visits (HF related and all cause) no significant difference between baseline and 6 months.	Decreased hospitalisations but no change LOS and ED.
White-Williams, 2015 (USA)	Cohort	Heart failure	3	235 intervention; 91 control	77 (Int); 71 (control)	47.7% male (Int); 52.7% male (control)	Remote monitoring system/device (not specified)	Manual	Active	Telephone	Not specified	The results of the tests indicated that there was no statistical significant difference in ED presentations and hospital readmissions between usual care and RPM group (Pearson chi-squared = 0.518 and 0.086, respectively, P > .05).	No significant difference
Williams, 2016 (USA)	Case control	Heart failure	2	105 intervention; 210 control	NR	43.8% male (Int); 46.7% male (control)	Dedicated RPM unit + peripheral devices	Manual	Active	Telephone	Condition-specific	No significant associations between RPM and hospital readmissions, $\chi 2$ = (1, n = 210, p-value = 0.71, phi = 0.71)	No significant difference
Zakeri, 2020 (UK)	Cohort	Patients with CIEDs (HF and AF)	34	1561; No AF - 616 interventoin; 595 control; Paroxysmal - 57 Intervention, 35 control; PP AF -134 intervential, 124 contorl	NR	NR	CIED	Automatic	NS	Not stated	All-cause and condition-specific	In patients with persistent/permanent AF, RM increased risk of recurrent cardiovascular (HR 1.40, 95% CI 1.06–1.85, P = 0.018] and HF-related (HR 2.05, 95% CI 1.14–3.69, P = 0.016) hospitalisations; For patients with paroxysmal AF and no AF, there was no difference in the risk of CV or HF-related hospitalisation (as a first or recurrent event) with RPM vs. usual care; When the dataset was truncated after the fifth hospitalisation (n = 103 CV hospitalisations excluded), the positive association between RPM and HF-related hospitalisations for patients with persistent/permanent AF remained statistically significant (HR 1.84, 95% CI 1.07–3.17, P = 0.027), while the association with CV hospitalisations was borderline significant (HR 1.32, 95% CI 1.00–1.75, P = 0.054).	Increased

CI = confidence interval; CIED: cardiovascular implantable electronic device; COPD = chronic obstructive pulmonary disease; CRT-D = cardiac resyncronisation therapy defibrillator; CV = cardiovascular; df= degrees of freedom; ED = emergency department; HF = heart failure; HR = hazard ratio; IBD=inflammatory bowel disease; ICD= implantable cardioverter defibrillator; Int= Intervention/RPM group; IQR = inter-quartile range; IRR = incidence rate ratio; LOS = length of stay; NS = not significant; OR = odds ratio; RCT = randomised controlled trial; RPM = remote patient monitoring; RR = risk ratio or risk reduction; SD = standard deviation

Supplementary Table 2. Participant vitals monitored by RPM device in each study

First author, Year	Patient Group or Disease	Comorbidities mentioned	BP	HR	SpO2	HbA1c	Weight	Temp	ECG	FEV1	Patient or informant questionnaires (e.g. symptoms)	Other
Celler, 2018	Chronic conditions (unspecified)	Yes	X	X	X			X	X	X		
Kenealy, 2015	Chronic conditions (unspecified)	Yes	X		X	X	X					
Orozco-Beltran, 2017	Chronic conditions (unspecified)	Yes	X		X	X	X			X		
Chatwin, 2016	Chronic lung disease (COPD and chronic respiratory failure)	Yes	X	X	X		X				X	
Ishani, 2016	CKD	Yes	X	X	X	X	X					
Ho, 2016	COPD	NS	X		X		X	X			X	Other "Vital signs" (NS)
Sink, 2018	COPD	NS									X	Breathing rating (better, worse, or
Achelrod, 2017	COPD	Yes			X					X	X	
Alshabani, 2019	COPD	Yes										Adherence - inhaler
Clarke, 2018	COPD	Yes	X		X		X	X			X	
Esteban, 2016	COPD	Yes		X	X			X			X	Activity + respiratory rate
Kessler, 2018	COPD	Yes										"Health status information"
McDowell, 2015	COPD	Yes	X	X	X						X	
Mirón Rubio, 2018	COPD	Yes	X	X	X							
Ringbæk, 2015	COPD	Yes			X		X			X	X	
Shany, 2017	COPD	Yes	X	X	X	X	X	X	X	X	X	
Soriano, 2018	COPD	Yes	X		X					X		oxygen therapy
Stamenova, 2020	COPD	Yes	X		X		X	X			X	
Udsen, 2017	COPD	Yes	X	X	X		X					
Vianello, 2016	COPD	Yes		X	X							
Walker, 2018	COPD	Yes	X	X	X			X				Respitartory measures (forced oscillation technique)
Bohingamu Mudiyanselage, 2019	COPD or Diabetes	Yes	X	X	X	X						
Nancarrow, 2016	Geriatric	Yes	X		X	X	X	X				Other "Vital signs" (NS)
Lanssens, 2017	Gestational hypertensive disorders	Yes	X				X					Activity
Lanssens, 2018	Gestational hypertensive disorders	Yes	X				X					Activity
van den Heuvel, 2020	Gestational hypertensive disorders	Yes	X								X	
Bingler, 2018	Heart disease - infants	NS			X		X					
Gingele, 2019	Heart failure	NS									X	
Hale, 2016	Heart failure	NS										Adherence - medication
Koehler, 2018	Heart failure	NS	X	X	X		X		X		X	
Nouryan, 2019	Heart failure	NS	X	X	X		X					
Thomason, 2015	Heart failure	NS	X	X	X		X				X	
White-Williams, 2015	Heart failure	NS									X	"Vital signs" (NS)
Agboola, 2015	Heart failure	Yes	X	X	X		X				X	
Amir, 2017	Heart failure	Yes										Lung fluid content
Comin-Colet, 2016	Heart failure	Yes	X	X			X				X	
Galinier, 2020	Heart failure	Yes	X	X	X		X		X		X	
Jenneve, 2020	Heart failure	NS	X	X			X					

Jimenez-Marrero, 2020	Heart failure	Yes					X					"heart failure signs & symptoms" not specified
Kalter-Leibovici, 2017	Heart failure	Yes	X	X			X					
Kao, 2016	Heart failure	Yes									X	"Vitals" (NS)
Koulaouzidis, 2019	Heart failure	Yes					X					
Kraai, 2016	Heart failure	Yes					X				X	
Leng Chow, 2020	Heart failure	Yes	X	X			X					
Mizukawa, 2019	Heart failure	Yes	X	X			X					
Nunes-Ferreira, 2020	Heart failure	Yes	X	X	X		X	X	X			Steps, body water content
Olivari, 2018	Heart failure	Yes	X	X	X		X		X			
Ong, 2016	Heart failure	Yes	X	X			X				X	
Pedone, 2015	Heart failure	Yes	X	X	X							
Pekmezaris, 2019	Heart failure	Yes	X	X	X		X					
Riley, 2015	Heart failure	Yes	X	X	X		X					
Srivastava, 2019	Heart failure	Yes	X	X	X		X					
Ten Eyck, 2019	Heart failure	Yes					X				X	
Wagenaar, 2019	Heart failure	Yes	X	X			X					
Ware, 2020	Heart failure	NS	X	X			X					
Williams, 2016	Heart failure	Yes	X	X	X		X					
Davis, 2015	HF, COPD	Yes		X	X		X					
Lyth, 2019	HF, COPD	Yes									X	Intake - medication
Persson, 2019	HF, COPD	Yes	X		X		X	X		X	X	
Martin-Lesende, 2017	HF, COPD or other chronic lung disease	Yes	X	X	X		X				X	Respiratory rate
Trucco, 2019	Home-ventilated neuromuscular patients	Yes		X	X							IPAP, EPAP, breathing patterns
Cross, 2019	Inflammatory bowel disease	NS									X	
De Luca, 2016	Nursing home patients; Mental health	Yes	X		X				X			
McElroy, 2016	Patients post surgery (cardiac)	Yes	X	X	X		X				X	
Rosner, 2018	Patients post surgery (orthopaedic)										X	
De Simone, 2019	Patients with CIEDs (AF)	Yes		X								Heart rhythm, device functioning, arrhythmic episodes
Böhm, 2016	Patients with CIEDs (HF)	Yes										Intrathoracic fluid
Boriani, 2017	Patients with CIEDs (HF)	Yes										Lung fluid content and atrial tachyarrhythmia,
Capucci, 2017	Patients with CIEDs (HF)	Yes		X								Heart rhythm, device functioning
Geller, 2019	Patients with CIEDs (HF)	NS		X					X			Heart rhythm, device functioning
Hansen, 2018	Patients with CIEDs (HF)	NS		X					X			Heart rhythm, device functioning
Kurek, 2017	Patients with CIEDs (HF)	Yes		X								ICD data - NS
Sardu, 2016	Patients with CIEDs (HF)	Yes		X								ICD data - NS
Tajstra, 2020	Patients with CIEDs (HF)	Yes	X	X					X			Heart rhythm, device functioning
Zakeri, 2020	Patients with CIEDs (HF and AF)	Yes	X	X					X			Heart rhythm, device functioning
Heidbuchel, 2015	Patients with CIEDs (unspecified)	NS		X					X			Heart rhythm, device functioning

Ricci, 2017	Patients with CIEDs (unspecified)	NS											ICD data - NS
Akar, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Amara, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning, atrial tachyarrhythmia
Buchta, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Bulava, 2016	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
D'Ancona, 2017	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
De Simone, 2015	Patients with CIEDs (unspecified)	Yes		X									Heart rhythm, device functioning
Ladapo, 2016	Patients with CIEDs (unspecified)	Yes		X									Cardiac monitoring - (NS)
López-Liria, 2020	Patients with CIEDs (unspecified)	NS	X	X						X			Heart rhythm, device functioning
Lu¨thje, 2015	Patients with CIEDs (unspecified)	Yes											Fluid index
Piccini, 2016	Patients with CIEDs (unspecified)	Yes											ICD data - NS (e.g. Heart rhythm, device functioning, arrhythmias)
Lew, 2018	Peritoneal dialysis patients	Yes	X				X						
Milan Manani, 2020	Peritoneal dialysis patients	Yes	X				X						
Sanabria, 2019	Peritoneal dialysis patients	Yes	X				X						Ultrafiltration profile, initial drainage
Flaherty, 2017	Schizophrenia	NS										X	
TOTALS			**49**	**52**	**39**	**6**	**44**	**10**	**13**	**7**	**29**		

AF = atrial fibrillation; BP = blood pressure; CIED: cardiovascular implantable electronic device; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; ECG = electrocardiogram; EPAP = expiratory positive airway pressure; FEV1 = forced expiratory volume-one second; HbA1c = glycated haemoglobin; HF = heart failure; HR = heart rate; ICD= implantable cardioverter defibrillator; IPAP = inspiratory positive airway pressure; NS = not stated; SpO2= oxygen saturation

Reporting checklist for systematic review and meta-analysis.

Based on the PRISMA guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the PRISMAreporting guidelines, and cite them as:

Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement

		Reporting Item	Page Number
Title			
	#1	Identify the report as a systematic review, meta-analysis, or both.	1
Abstract			
Structured	#2	Provide a structured summary including, as applicable:	2

summary		background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number	
Introduction			
Rationale	#3	Describe the rationale for the review in the context of what is already known.	3
Objectives	#4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3
Methods			
Protocol and registration	#5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address) and, if available, provide registration information including the registration number.	3
Eligibility criteria	#6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rational	4
Information sources	#7	Describe all information sources in the search (e.g., databases with dates of coverage, contact with study authors to identify additional studies) and date last	3

		searched.	
Search	#8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	#9	State the process for selecting studies (i.e., for screening, for determining eligibility, for inclusion in the systematic review, and, if applicable, for inclusion in the meta-analysis).	4
Data collection process	#10	Describe the method of data extraction from reports (e.g., piloted forms, independently by two reviewers) and any processes for obtaining and confirming data from investigators.	4
Data items	#11	List and define all variables for which data were sought (e.g., PICOS, funding sources), and any assumptions and simplifications made.	5
Risk of bias in individual studies	#12	Describe methods used for assessing risk of bias in individual studies (including specification of whether this was done at the study or outcome level, or both), and how this information is to be used in any data synthesis.	5
Summary measures	#13	State the principal summary measures (e.g., risk ratio, difference in means).	5-6
Planned methods of	#14	Describe the methods of handling data and combining results of studies, if done, including measures of	5-6

analysis		consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	#15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	n/a but mention this bias on p.10
Additional analyses	#16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
Results			
Study selection	#17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6
Study characteristics	#18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citation.	Supplementary Table 1
Risk of bias within studies	#19	Present data on risk of bias of each study and, if available, any outcome-level assessment (see Item 12).	8
Results of individual studies	#20	For all outcomes considered (benefits and harms), present, for each study: (a) simple summary data for each intervention group and (b) effect estimates and confidence intervals, ideally with a forest plot.	Supplementary Table 1
Synthesis of results	#21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	6-8

Risk of bias across studies	#22	Present results of any assessment of risk of bias across studies (see Item 15).	n/a but mention this bias on p.10
Additional analysis	#23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	6-11
Discussion			
Summary of Evidence	#24	Summarize the main findings, including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., health care providers, users, and policy makers	8-10
Limitations	#25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review level (e.g., incomplete retrieval of identified research, reporting bias).	10
Conclusions	#26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	10
Funding			
Funding	#27	Describe sources of funding or other support (e.g., supply of data) for the systematic review; role of funders for the systematic review.	11