

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

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## 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 2050 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 patients with cardiovascular disease and COPD. 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.

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## INTRODUCTION

Many people find it challenging to self-manage complex and comorbid conditions and identify warning signs of exacerbation.

## Strengths and limitations of this study

- 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 subanalyses and new evidence, particularly for patients with chronic obstructive pulmonary disease and monitoring using implanted devices.
- Due to heterogeneity of included studies we were unable to perform a meta-analysis.

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.<sup>1</sup> 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.<sup>2</sup> Data can be collected automatically (eg, 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 (eg, ventricular tachycardia or fibrillation).<sup>3</sup> Non-invasive interventions involve the transmission of data,



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such as body weight, blood pressure or pulse oximetry<sup>4</sup> and are used commonly in patients that require long-term self-management support (eg, patients with heart failure).<sup>5</sup> 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, video consultation or home visits.

Chronic diseases are associated with high rates of unplanned acute hospital use, even more so when the patient has comorbid conditions.<sup>6</sup> This represents a substantial cost to the health system. For example, in Australia there are more than 748 000 potentially avoidable hospitalisations 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.<sup>7</sup> 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 person's condition enabling issues to be resolved out of hospital thereby reducing the need for urgent hospital admissions.<sup>8</sup> Existing research shows that for RPM to be cost-effective it needs to reduce acute hospital use.<sup>9</sup> 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.<sup>5 10–14</sup> Furthermore, these reviews were largely published more than 5 years ago. Hence, there is limited evidence for the effect of RPM using newer technologies such as implanted devices and for other disease conditions.<sup>15</sup> 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 5 years (2015–2020). Supporting our decision to examine research from the last 5 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.<sup>16</sup> The protocol for our review was registered with PROSPERO, international prospective register of systematic reviews.<sup>17</sup>

### Search strategy

To identify relevant articles we conducted searches of three electronic databases: PubMed (MEDLINE) (1966–2020),

### 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])
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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 utilisation. Searches were first conducted in July 2019 and updated in October 2020.

### 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-RPM 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 (ie, 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 (eg, 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 (MLT and Maryama Bihi) who were also blinded to each other's selections. Where necessary the full text was used to determine eligibility. A third

**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, randomised controlled trial, 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 (eg, blood pressure, heart rate)
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 (eg, tablet, dedicated remote monitoring unit)
Data collection	Whether biometric data was collected manually or automatically
Data review	Whether biometric data was reviewed by clinical staff passively (eg, there was an automated alert system) or actively (eg, 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 remote monitoring increased, decreased or had no significant effect on acute care use in the study

RPM, remote patient monitoring.

researcher (CLS, EET or LJC) 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 (MLT) extracted the data and a second author (EET)

validated the accuracy by checking a 20% random selection of the data.

### Quality assessment

Quality of the included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklists.<sup>18</sup> 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.<sup>19</sup> 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 (MLT and EET) 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 care 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 (ie, invasive vs non-invasive).

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

## RESULTS

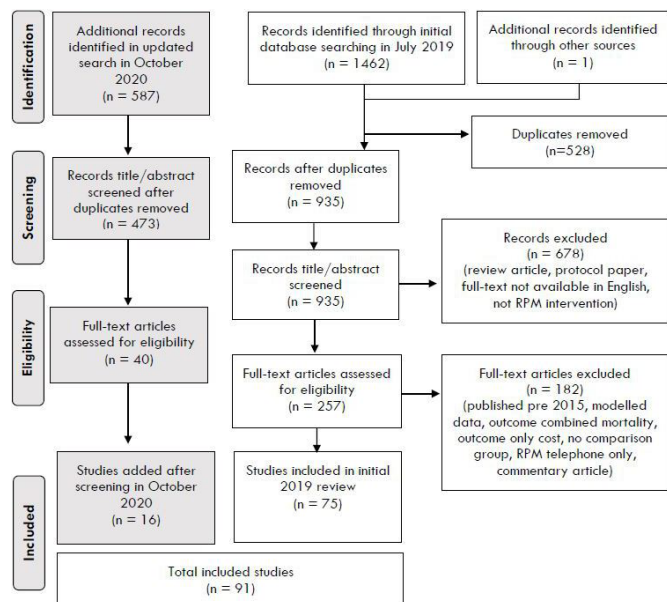
### Study selection

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](#)).

### Study characteristics

Included studies were primarily conducted in Europe (n=52, 57%), followed by the USA (n=26, 29%). Most studies were 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<sup>21</sup> to 92 566<sup>22</sup> 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 6 months in the majority of studies (n=62, 68%), however, 12% (n=11) had a follow-up time of 3 months



**Figure 1** Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of screening process and study selection. RPM, remote patient monitoring.

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.<sup>23 24</sup> 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 summarised in online supplemental 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 comorbid 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 online supplemental 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 (ie, automated alert) and those that had active data review (eg, 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.

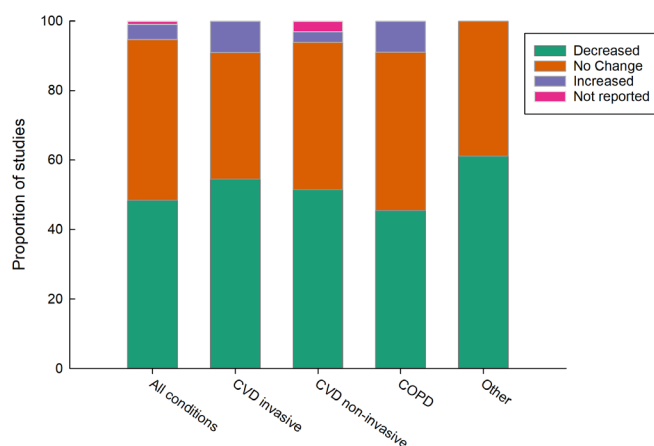
In all studies out-of-range biometrics triggered clinical communication. Some interventions involved supplementary services from staff, such as assisting with education and health literacy. Modes of communication with patients included telephone (n=37, 41%), videoconferencing (n=13, 14%) and asynchronous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

## Technology

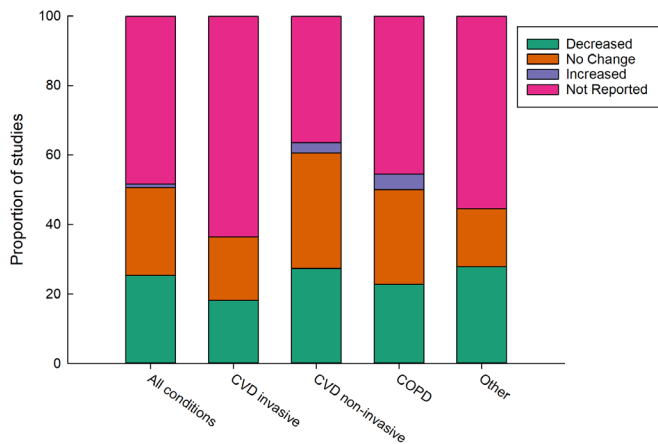
The technology for RPM was either a dedicated unit or hub (n=35, 39%); CIEDs including ICDs, cardiac resynchronisation therapy (CRT) including those with defibrillators (CRT-Ds) and pacemakers (n=22, 24%); tablet computer applications (n=13, 14%); telephone or smartphone applications (n=9, 10%); websites (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 2–4). The majority of studies set a significance level of 5% for concluding



**Figure 2** Effect of remote patient monitoring on hospitalisation by condition type. COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease.

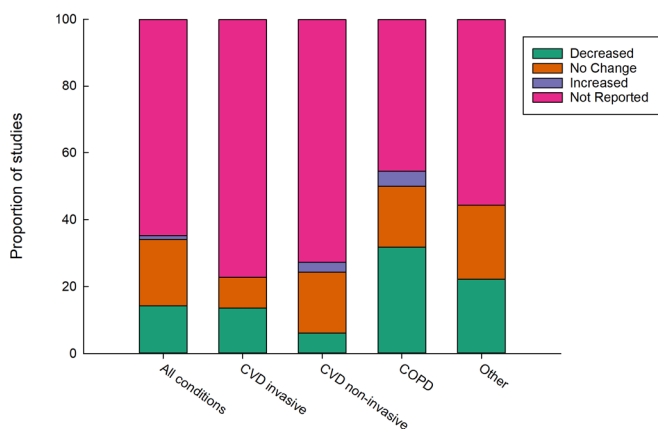


**Figure 3** Effect of remote patient monitoring on length of stay by condition type. COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease.

that there was a difference between groups, however individual study details on this can be viewed in online supplemental table 1.

#### CVD invasive

CVD using invasive monitoring appears to be most effective at reducing hospitalisations (figure 2). Eleven RCTs have been conducted.<sup>25–35</sup> Of these, only three demonstrated a significant reduction in acute care use with a reduction in length of hospital stays<sup>26</sup> 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<sup>31</sup>; hazard ratio (HR) 0.6, 0.42–0.79, p=0.002).<sup>35</sup> 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<sup>22 36</sup> had very large



**Figure 4** Effect of remote patient monitoring on emergency department presentations by condition type. COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease.

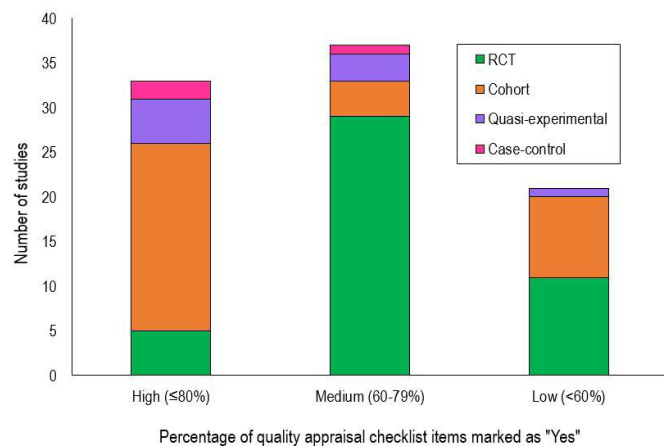
sample sizes with matched controls (n=37 742 and 92 566, respectively). In fact, Piccini *et al*<sup>22</sup> had a larger sample size (n=92 566) than all the other CVD invasive populations combined (n=49 113). Both Piccini *et al*<sup>22</sup> and Akar *et al*<sup>36</sup> reported an 18% lower risk of all-cause hospitalisation in the RPM groups with both studies reporting identical adjusted HRs of 0.82 (95% CI: 0.80 to 0.84; p value:<0.001). Piccini *et al*<sup>22</sup> also reported a shorter mean length of hospital stay of approximately 3 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*<sup>37</sup> 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 2 days less in hospital compared with control participants (RPM group=mean 3.8 days per year, 95% CI: 3.5 to 4.1 vs 5.6 days per year, 95% CI: 5.2 to 6.0).<sup>38</sup> However, similarly large RCTs reported no change in the number of hospitalisations or length of stay.<sup>39 40</sup> 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 (eg, cardiologist, general practitioner (GP), nurse) and tailored support using a predefined algorithm.<sup>38</sup>

#### Chronic obstructive pulmonary disease

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;<sup>41 42</sup> Witt Udsen *et al*<sup>42</sup> had the largest sample size (n=578/647 intervention/control) of the trials. Across the RCTs, COPD-related hospitalisations differed from a mean difference of 10 fewer admissions in the intervention group of Sink *et al*<sup>43</sup> over 8 months (absolute risk reduction=11.6%; RPM=6 hospitalisations vs non-monitored=16 hospitalisations) to a slight increase in admissions over a 6-month period (RPM admissions=0.63 vs 0.32 in non-monitored mean difference: 0.32, p value: 0.026).<sup>41</sup> 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 hospitalised due to all-causes (−15.16%, p<0.0001), and COPD-specific admissions (−20.27%, p<0.0001).<sup>44</sup> On average,



**Figure 5** Number of articles by proportion of 'Yes' responses to items on the Joanna Briggs Institute critical appraisal checklists, separated by study type. RCT, randomised controlled trial.

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 to 4.12,  $p=0.016$ ).<sup>45</sup> Reductions in hospital use were also seen in RPM groups with multiple chronic conditions;<sup>46</sup> mental health;<sup>47 48</sup> and patients with home-ventilated neuromuscular conditions.<sup>49</sup>

#### Study quality

The overall quality of studies as assessed by the JBI critical appraisal checklists was medium to high (figure 5).<sup>18</sup> 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.

## 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 with other disease conditions and non-invasive monitoring. Only four studies reported higher acute hospital use resulting from RPM.<sup>32 41 42 50</sup> Around 70% of included studies were for CVD, COPD or comorbid 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 with 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 (eg, cohort studies) and comparison of effectiveness of different RPM interventions. While 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*<sup>8</sup> 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 ( $n=34259/58307$  intervention/control) by Piccini *et al*<sup>22</sup> found that invasive cardiac monitoring significantly reduced both all-cause hospitalisations and the resultant length of stay.

There has been a number of previous reviews of RPM for COPD populations.<sup>13 15</sup> One included six primary studies (both RCTs and other study designs) of which four reported reduction in hospital admissions.<sup>15</sup> Our review included 22 studies on RPM of COPD and comorbid 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 populations. This increase may be 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.<sup>44</sup>

### Implications for practice

#### Effect of RPM on subpopulations

Clinical outcomes for patients on remote monitoring have been more effective for subpopulations when compared with the whole of population. The largest study to date,<sup>22</sup> reported that RPM was associated with reductions in all-cause hospitalisation. While this association held across all implanted devices, it was most evident for cardiac

resynchronisation 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.<sup>36</sup> 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 applications were shown to have better compliance to monitoring than those using a web page.<sup>51</sup> 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.<sup>13</sup>

### 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.<sup>52</sup> 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.<sup>53</sup> 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*<sup>38</sup> took by involving multiple healthcare providers (eg, 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.<sup>5 12 40 54</sup> 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 (eg, comorbidities), intervention (eg, inclusion of educational component, invasive vs non-invasive monitoring, active vs passive

review) and study differences (eg, all-cause vs disease-specific acute hospital use). This makes generalisability 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*<sup>34</sup> compared two trials and found that 1-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.<sup>55</sup>

### Future research

Further investigation is needed to identify subpopulations and intervention characteristics that will enhance the effectiveness of remote monitoring. Policymakers 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 (eg, 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.<sup>56</sup>

### 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 the 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 subpopulations when compared with 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 with 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 (eg, atrial fibrillation) rather than relying on physiological signs (eg, 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.

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