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# BMJ Open

## Factors influencing effectiveness of remote patient monitoring interventions: A realist review

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# Factors influencing effectiveness of remote patient monitoring interventions: A realist review

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## Abstract (258 words)

*Objectives:* Remote patient monitoring (RPM) is an underutilised telehealth intervention that can enhance self-management of chronic disease and reduce acute care use. However, effectiveness of RPM interventions varies within and between populations. This study aimed to explain the variation in outcomes related to RPM interventions.

*Design:* Systematic search and realist review

*Participants:* A systematic literature review was undertaken 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.

*Primary and secondary outcome measures:* Realist review methodology was used to evaluate 91 studies that reported on RPM interventions and the impact on acute hospital use. Outcomes were evaluated to determine contextual factors and potential mechanisms that led to variation in outcomes of acute hospital use.

*Results:* We found that across a broad range of RPM interventions 31 factors emerged that are likely to impact the effectiveness of RPM innovations. These were synthesised into six theories of intervention success: 1) targeting populations at high risk; 2) accurately detecting a decline in health; 3) providing responsive and timely care; 4) personalising care; 5) enhancing self-management and, 6) ensuring collaborative and coordinated care.

*Conclusion:*

While RPM interventions are complex, if they are designed with patients, providers and the implementation setting in mind and with the key variables identified within this review incorporated, it is more likely that they will be effective at reducing acute hospital events.

*Registration:* The protocol for our review was registered (#CRD42020142523) with the Prospective Register of Systematic Reviews (PROSPERO).

### Strengths and limitations

- Our review was strengthened by a comprehensive search and inclusivity of diverse RPM interventions across a broad spectrum of conditions and contexts.
- The novel use of realist review methodology and development of theory-based constructs helped to systematically identify factors impacting upon implementation.
- Included studies within our review had multiple study design issues. Typically, with many of these studies it is not possible (or ethical) to blind participants. Therefore, selection bias may have effected results if health professionals pragmatically selected more willing or engaged patients to participate in the trials.
- While our focus was on acute care use, other aspects of care may have been overlooked that relate to care quality.

## Introduction

Non-communicable diseases such as heart disease, chronic obstructive pulmonary disease (COPD), and diabetes accounts for over 70 per cent of global deaths each year.<sup>1</sup> Combined with the added challenge of ageing populations, health systems internationally are under enormous strain to support growing numbers of chronically unwell people.<sup>2</sup> One of the main drivers of healthcare costs for chronically ill patients results from acute hospital admissions due to their intense resource requirements.

Remote patient monitoring (RPM) is a telehealth innovation that offers significant opportunities to increase the timeliness of care, enhance health outcomes, and potentially reduce hospitalisations and associated healthcare costs.<sup>3, 4</sup> RPM uses technology to observe a patient's physiological (e.g. heart rate, blood pressure) and behavioural (e.g. medication adherence, physical activity) information from a distance.<sup>5</sup> With support, many individuals could effectively self-manage chronic conditions in the community.<sup>6</sup> Further, if alerted early, healthcare providers could intervene when a person's health is declining, potentially preventing costly escalations to hospital. Health professionals can routinely monitor a patient's health data and/or be alerted when measurements exceed a pre-determined threshold. This allows for early intervention and ideally prevention of further exacerbation of a condition. RPM can benefit people with chronic illness as well as other population groups that benefit from continuous monitoring such as the frail and elderly, neonates or post-surgical patients.<sup>5</sup>

Despite the potential benefits of RPM, investigations into its clinical and cost effectiveness have provided mixed results to date. For example, the impact of RPM on the heart failure population has resulted in multiple systematic reviews<sup>7</sup>, meta-analyses<sup>8, 9</sup>, and reviews of reviews.<sup>10, 11</sup> These reviews are generally positive about the potential benefits for patients and health services from RPM services,<sup>7, 8, 10, 12</sup> but others also report limited or no effect<sup>9</sup> on reducing morbidity and mortality. A 2018 Cochrane review reported no difference in all-cause mortality in remotely monitored patients with heart failure and a change in hospitalisations ranging from a 64% decrease to a 60% increase.<sup>9</sup> In our recent review<sup>13</sup>, we provided a synthesis of the available evidence for the effect of RPM on acute care use including hospital admission events, hospital length of stay, and emergency department presentations. We found that RPM was reported to reduce acute care use in approximately 45% of studies. Remaining studies largely reported no change; however, some reported an increase in acute care use. The included 91 studies covered multiple chronic conditions, countries and health care organisations and used various technology and models of care. While RPM can have a positive impact on patient outcomes, certain enablers are needed. Clinicians, researchers, and policymakers require more guidance on how to design and implement RPM-facilitated models of care to achieve the greatest benefit. Consequently, further analysis is required to understand underlying mechanisms causing such variation in RPM interventions.<sup>14</sup>

We sought to understand what causes variation in outcomes from RPM interventions. While our original review was able to determine the observed effect of RPM on acute care use, we further analysed the existing evidence to try to explain why these effects were observed. Specifically, this study aims to (1) identify factors of RPM interventions that relate to increased and decreased acute care use, and (2) develop recommendations for future RPM intervention design and implementation.

## Methods

To achieve the aims of this study we reviewed the same 91 articles included in our recent RPM systematic review, using realist review methodology to identify factors that determine intervention success and failure in various contexts.<sup>13</sup> Realist review methodology enables exploration of how, why and for whom interventions do and do not work. The basic tenant of realist philosophy is that the effectiveness of an intervention is impacted by the context in which it is implemented which will trigger mechanisms that result in intended and unintended outcomes.<sup>15</sup> Realist reviews are particularly helpful for complex interventions like RPM interventions where the effectiveness is impacted by multiple interacting components such as the intervention design, users, interpersonal relationships and institutions and settings where the intervention is delivered. This review was guided by the work of Pawson et al (2005)<sup>16</sup> and followed guidelines outlined by the Realist and Meta-narrative Evidence Synthesis: Evolving Standards (RAMESES; Appendix A)<sup>17</sup>.

We used data from our recent systematic review that compared acute care use between individuals who were and were not monitored using RPM. In brief, search terms for remote monitoring and acute care utilisation were used across three electronic databases: PubMed (MEDLINE)[1966-2020], EMBASE (OvidSP)[1974-2020], and CINAHL (EBSCOHost)[1982-2020]. The search, conducted in October 2020, included articles published in the last five years (2015-2020). Articles were included if they used RPM to monitor an individual's biometrics (e.g. heart rate, blood pressure) from a distance while they are not in hospital. No restrictions were placed on patient age, or disease conditions however full-text studies had to be available in English. Complete details of the original systematic review have been described elsewhere.<sup>13</sup>

### Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

### Evidence synthesis

According to the methodology described by Pawson et. al.<sup>16</sup> information was extracted that related to context (settings, populations, intervention delivery); outcomes (positive, negative or null effect on outcome of hospital use), and potential mechanisms or reasons behind the results (e.g. author's interpretation as to why the interventions did or did not work). These data were recorded in an Excel spreadsheet to facilitate a structured analysis. Two researchers (ET, MT) independently extracted this data.

The researchers then collectively examined the articles to detect patterns and developed a compendium of explanatory factors observed in the RPM studies. The researchers compared and discussed their identified factors that led to increased or decreased acute care use being reported in the studies. Findings were then combined into a table showing the number of studies proposing each mechanism and grouped by outcome (e.g. increased or decreased acute care use).

The two researchers then jointly mapped recurrent patterns into explanatory context-mechanism-outcome (CMO) diagrams to illustrate how the different factors interact. Literature was also examined for opposing or conflicting viewpoints. These CMO diagrams were discussed with a third member of the research team (LC) to confirm consistent and logical development. Key findings were synthesised into overarching themes, which are referred to as 'theories' in the realist review approach.<sup>16</sup> Finally, a list of recommendations was developed from the findings and ordered by context to guide future RPM intervention design and implementation.

## Results

Ninety-one articles from our previous review were evaluated to determine why RPM increased, decreased, or had no effect on acute care use. Thirty-one factors were identified and mapped onto two outcomes: 1) increased hospital use (21 factors) and 2) reduced hospital use (10 factors) (Figures 1 & 2). Factors were also ordered by the frequency of articles that reported them as possible influences on outcomes (represented by the size of each factor in Figure 1 and 2).

### [Insert Figure 1]

**Figure 1** Factors associated with RPM intervention studies that reduced acute care use.

The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring

### [Insert Figure 2]

**Figure 2** Factors associated with RPM interventions studies that increased acute care use.

The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

RPM: remote patient monitoring; Pt: patient

### Theories about how RPM works

It was identified that successful RPM interventions, in this case those interventions that successfully reduced acute care use, were those that: 1) *target populations at high risk*; 2) *accurately detect a decline in health*; 3) *were responsive and provided timely care*; 4) *provided personalised care*; 5) *enhanced self-management* and, 6) *ensured collaborative and coordinated care*. Each of these theories of intervention success are described below.

#### Target populations at high risk

Appropriate selection of patients for RPM is crucial if a change in acute care use is to be achieved. RPM interventions are likely to have more pronounced effects on acute care use when they are targeted towards populations with a high risk of hospitalisation (e.g. moderate-severe disease severity, multiple comorbidities).<sup>18</sup> Further, it is important for the intervention to be timed with periods of high-risk readmissions (e.g. the first 90 days post an index event). Delaying the delivering of RPM devices to patients may reduce the effect.<sup>19</sup>

Patients who are more likely to present to hospital multiple times have a greater chance of reducing admissions due to more timely interventions. In practice, however, clinicians may have reservations about remotely assessing their most vulnerable and unwell patients. As described by Geller et al.,<sup>20</sup> *“in clinical practice telemedicine seems to be used mainly in patients with better prognosis, probably due to the belief that those who live longer may receive more (i.e. prolonged) benefit from*



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3 *telemonitoring than sicker patients who should be seen in the office more frequently”* (pg. 1124).  
4 Consequently, clinicians may require additional information on how RPM can be safely delivered in  
5 high-risk cohorts.  
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### 10 **[Insert Figure 3]**

11 *Figure 3. Proposed context-mechanism-outcome: target population*

#### 12 13 14 15 ***Accurately detect a decline in health***

16 RPM needs to accurately predict disease exacerbations by detecting a change in symptoms that  
17 relate to health deteriorations. This has been a challenge in certain populations such as COPD and  
18 heart failure patients which may have unpredictable disease progression. In the COPD population,  
19 multiple studies reported trying to determine the measurement (e.g. spirometry, oximetry, or a  
20 combination) which would mark the onset of an exacerbation,<sup>21-24</sup> however, none came to a  
21 definitive conclusion.<sup>25</sup> RPM can be used in these population groups to longitudinally track the  
22 progression of disease and develop parameters to be tested as predictors for future interventions.<sup>26</sup>  
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26 In the heart failure population, physiological signs may not provide adequate warning of  
27 decompensation. Readmission in this cohort can be a complex interplay of multiple factors and is  
28 often not solely limited to physiological variables.<sup>27</sup> If deterioration occurs too quickly, there is  
29 limited opportunity to intervene.<sup>28</sup> Therefore, more investigation is required to try and accurately  
30 predict health declines for individual patients and accurately pin-point the best way for RPM to be  
31 used to support this patient population.  
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35 Implantable devices (e.g. pacemakers) have an additional advantage; continuous monitoring enables  
36 undiagnosed co-morbid conditions such as atrial fibrillation to be detected enabling pre-emptive  
37 intervention.<sup>29</sup> It can also improve the efficiency of outpatient clinical care by detecting device or  
38 lead malfunctions earlier.<sup>30</sup>  
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#### 43 ***Provide timely care via a responsive system***

44 Any benefit from RPM is dependent on patients 1) using the system (e.g. timely data entry) and, 2)  
45 providers taking appropriate and equally timely action when out-of-range readings occur.<sup>29</sup>  
46 Therefore, RPM systems that use automated data entry wherever possible are preferable as they  
47 can reduce errors and delays due to manual entry. As technology improves, smartphone-based  
48 programs are likely to replace standard RPM equipment which may result in more consistent,  
49 accurate and timely data from patients.<sup>18</sup> For innovations that rely on manual data entry, RPM  
50 innovations need to be easy to use (e.g. enables efficient data entry, transportable) and useful for  
51 patients to ensure long term use and engagement.<sup>31</sup> Additionally, regular monitoring is required. For  
52 example, Srivastava et al.<sup>18</sup> routinely monitored data for abnormalities or lack of responses; if a  
53 patient did not submit data for three days, a call was initiated by nursing staff.  
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58 On the staff end, RPM alerts need to be actioned with timely and appropriate responses; the speed  
59 of decision-making and frequency of monitoring is paramount.<sup>32</sup> A fast response often requires  
60 frequent contact with patients and effective bi-directional communication pathways between staff

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3 and patients. For example, Trucco et al.<sup>33</sup> facilitated communication between families and the on-  
4 call team via a dedicated phone number or email address. Multiple studies report the importance of  
5 dedicated care (e.g. providing an RPM nurse or dedicated case manager) in improving response  
6 time.<sup>32, 34-37</sup> This is supported by the literature with findings that patients who received either basic  
7 or intensive case management spend less time in hospital than those without.<sup>38</sup> “Fast tracked”  
8 access to primary care providers was used in the intervention reported by Pedone et al.<sup>39</sup> when  
9 abnormalities were presented, or new symptoms arose. They reported that a new model of care,  
10 rather than simply implementing a new technology, was required to obtain sizable benefits in terms  
11 of hospitalisation outcomes.<sup>39</sup> Where possible, RPM should be embedded into the system and  
12 provide seamless interaction between patients and the healthcare system with minimal  
13 encumbrance on both ends.<sup>18</sup>  
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19 **[Insert Figure 4]**

20 *Figure 4. Proposed context-mechanism-outcome: timely care*

### 21 ***Provide personalised care***

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26 Providing a patient-centric and personalised approach was also an important factor in determining  
27 the success of an RPM intervention in reducing acute care use.<sup>18</sup> Firstly, the development of the RPM  
28 innovation needs to be co-designed with patients and their families to ensure it meets their needs  
29 and maximise acceptance and uptake.<sup>40</sup> Training patients on how to use the device will likely also  
30 need to be personalised and at times repeated. RPM alerts can also be personalised by using  
31 individual data to determine alert thresholds. Koelher et al.<sup>41</sup> recommended defining a risk category  
32 for each individual patient based on their positive results (derived from biometric data). One study  
33 author requested personalised parameters and treatment guidelines from each patient’s treating  
34 physician.<sup>42</sup> Determining appropriate parameters for RPM applications (personalised or not) enables  
35 the treating team to be alerted to any biometric measurements that fall outside of the personalised  
36 parameter ranges. To enable these personalised parameters to be developed physicians need to be  
37 engaged in the RPM process for their patient early. The response by the RPM monitoring team also  
38 needs to be tailored; considering the person’s medical, social and emotional needs.  
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### 45 ***Enhance self-management***

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47 To successfully reduce acute care use, RPM interventions should include support and education to  
48 increase self-management skills. Through developing knowledge, skills and positive behaviours (e.g.  
49 medication adherence), patients are more likely to be able to effectively manage their condition  
50 with the aid of RPM.<sup>43</sup> Additionally, increased awareness of signs and symptoms of disease  
51 progression that often occurs when patients use RPM can prompt them to contact their healthcare  
52 provider for timely management.<sup>43</sup> Providing feedback from RPM data in a way that empowers  
53 patients to take control of their own health is important. Koelher et al.<sup>41</sup> reported that this needs to  
54 be a comprehensive approach including education and patient involvement when developing  
55 management strategies. In some instances, RPM interventions were discontinued once patients  
56 were able to correctly correlate their personal symptoms and seek help when required.<sup>42</sup>  
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58 Conversely, some RPM interventions that were unsuccessful in reducing hospitalisation events  
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3 reported patients becoming overly reliant on the RPM team, for instance alerting the team know  
4 when an issue arose rather than developing autonomous self-management skills for their condition.  
5 Additionally, some known important factors such as medication adherence were not always  
6 measured and present a lost opportunity in many RPM innovations. Medication adherence and  
7 timely changes to medications are reported to confer substantial benefits for patients.<sup>41</sup>  
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10 **[Insert Figure 5]**  
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14 *Figure 5. Proposed context-mechanism-outcome: self-management*  
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### 18 **Ensure collaborative and coordinated care**

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20 Successful RPM studies demonstrated increased connection and communication between  
21 healthcare staff and patients.<sup>30</sup> Multidisciplinary team-based interventions that combine feedback  
22 (automated and/or provider-initiated) with other approaches (e.g. coaching, motivational  
23 interviews, and shared decision-making) are more likely to result in improvement in adherence.<sup>44</sup>  
24 Involvement of primary care is crucial. As high-risk patients are often managed by primary and  
25 specialty care, both hospital and primary care settings should be involved in RPM interventions.<sup>45</sup>  
26 Involvement of key stakeholders is required to improve continuity of care.<sup>46</sup> Beyond healthcare  
27 professionals, the RPM intervention should also aim to include families and carers as key  
28 stakeholders in the long-term management of the person's condition. To increase primary carers'  
29 acceptance of and adherence to RPM, they must be involved very early on. To institute an initial  
30 change of role, staff incentives (e.g. financial payments) may be required.<sup>26</sup> Additionally, nursing  
31 staff should be considered as having leading roles in RPM interventions.<sup>47</sup> Further, institutional  
32 support is required for these initiatives and reorganisation of care processes should be carefully  
33 planned and implemented.<sup>47</sup>  
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### 38 **Factors that resulted in increased acute care use**

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40 A range of factors were identified as having influence on hospital use (increasing admissions) and  
41 subsequent negative clinical outcomes. For example, multiple study authors reported slow alert  
42 response times (N=6)<sup>31, 48-52</sup> and low patient or clinician adherence (N=11)<sup>18, 19, 27, 31, 44, 53-58</sup> as  
43 important factors resulting in no change or an increase in acute care use in the RPM group. There  
44 also appears to be a delicate balance between providing a supportive environment that empowers  
45 patients to self-manage versus having patients become reliant on the RPM device and/or the  
46 monitoring team.  
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### 51 **Recommendations for RPM**

52 We synthesised multiple recommendations to assist in the design and implementation of RPM  
53 interventions (Figure 6).  
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57 When designing RPM devices, it is crucial that the measured biometrics accurately predict disease  
58 exacerbations. Alert thresholds need to be carefully determined to ensure they are sensitive to  
59 physiological changes without being too high, and where possible tailored to the patient and disease  
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3 state. Further, the transmission of data needs to be reliable, and if possible, automatic.  
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5 It is essential that RPM devices are co-designed with consumers and providers to improve usability  
6 and engagement with the RPM system. It is likely that making the device interactive and building in  
7 feedback loops between the patient and clinician will enhance engagement. However, if this  
8 increases the provider's workload it may discourage provider engagement. Multidisciplinary team  
9 interventions that combine feedback with other approaches like patient education, motivational  
10 interviewing, coaching or shared decision-making are likely to be more effective long-term.<sup>59</sup>  
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14 At the organisation level, having dedicated professionals responsible for monitoring data and  
15 communicating with patients and the healthcare team can improve the timeliness and coordination  
16 of care. Studies with nursing staff in these leading and case-management roles appeared to be more  
17 effective.<sup>47</sup> RPM also needs to be embedded into the health system to provide seamless interaction  
18 between patients and the healthcare system. This may require reorganisation of care and additional  
19 resources (physical and personnel) to support the intervention.  
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25 **[Insert Figure 6]**

26 *Figure 6. Recommendations to enhance RPM and reduce acute care use*  
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## 30 Discussion

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32 We found that RPM interventions were successful at reducing acute care use when they  
33 incorporated a number of elements including; accurately predicting a decline in health or disease  
34 exacerbation, timely response to alerts, personalised patient parameters, and a focus on enhancing  
35 patient self-management. Additionally, RPM needed to improve the continuity of care by enhancing  
36 collaboration between specialists and primary care. To the best of our knowledge, this is the first  
37 review to elucidate why some RPM interventions are more successful than others in reducing acute  
38 care use.  
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41 RPM interventions are complex because they typically involving multiple components (e.g. data  
42 collection, education, feedback) and various stakeholders across different settings (e.g. community,  
43 primary and tertiary care). Given the complexity of RPM interventions, it is perhaps unsurprising that  
44 RPM studies have resulted in so much variation in the effects demonstrated regarding changes in  
45 acute care use. To date, much of the focus of RPM innovations has been on the design and  
46 development of the technology.<sup>60, 61</sup> While functioning technology that accurately detects a decline in  
47 health is important, to deliver significant benefits RPM alerts must also lead to an actionable and  
48 timely responses. To achieve positive results at the healthcare system level, RPM interventions  
49 require a change to the *model of care* rather than simple technology implementation.<sup>62</sup>  
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52 To be successful, the right patients need to be recruited at the right time. Patients with greater  
53 disease severity and at high risk of readmissions appear to confer the greatest benefit of RPM  
54 interventions in terms of reduced hospitalisation.<sup>63</sup> For instance, a recent consensus statement from  
55 the Heart Failure Society of America<sup>64</sup> broadly concluded that heart failure RPM had the most impact  
56 when patients were most at risk (e.g., recent hospitalisation, prone to fluid overload, and struggles  
57 with medication adherence). Additionally, RPM should target patients who are willing and likely to  
58 adhere with RPM regimes. Huygens suggests there is a relationship between perceived disease  
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3 controllability and patients' willingness to self-monitor.<sup>65</sup> Patients with diabetes, asthma and  
4 hypertension were most willing to self-monitor. In contrast, patients with rheumatism, migraines  
5 and other neurological disorders were less willing. The intervention design can facilitate engagement  
6 and use. Hong and Lee<sup>63</sup> determined that interventions with an educational component such as self-  
7 management programs have greater effects. Another consideration is the patient's social  
8 circumstance. One study found that RPM significantly improved outcomes for socially isolated  
9 patients,<sup>66</sup> potentially due to the delay in care access that these patients may face. Conversely, for  
10 socially connected patients, outcomes appear to be enhanced by training caregivers.<sup>28, 67</sup>

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13 In primary care, tailoring advice and monitoring symptoms or exacerbations by keeping logs are key  
14 self-management support strategies which are routinely used (i.e. food and blood sugar diaries for  
15 diabetics).<sup>68</sup> The use of RPM can enhance tailored self-management strategies by providing and  
16 visualising data to explain the impact of an individual's health behaviour on their vital signs. This can  
17 improve a patient's understanding of why and how they need to modify their behaviour.<sup>59</sup> Patients  
18 with low levels of health literacy have the most to gain in improving their self-management  
19 knowledge and skills with such interventions. Interventions based on health behaviour models and  
20 personalised coaching were most successful.<sup>69</sup> The findings of this review parallel some of the  
21 themes in a review of patient experiences of RPM by Walker et al.<sup>70</sup> Similarly, self-management and  
22 early identification of clinical exacerbations were key to preventing hospitalisation. From the patient  
23 perspective, self-management was achieved by increasing confidence and providing a sense of  
24 safety. Shared decision making was identified as a key mechanism to preventing hospitalisation.

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27 Patients have previously reported concerns about being lost in the data or losing interpersonal  
28 connections with health professionals and a reluctance to try something new, especially if unfamiliar  
29 with technology.<sup>70</sup> Our findings substantiate the importance of co-designing RPM interventions with  
30 consumers to ensure they are easy to use and provide useful feedback to maintain adherence and  
31 engagement. Building rapport, providing training (sometimes multiple times) and having a two-way  
32 interactive relationship between the patient and the RPM team is crucial.

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34  
35 Included studies within our review had multiple study design issues. Typically, with many of these  
36 studies it is not possible (or ethical) to blind participants. Therefore, selection bias may have effected  
37 results if health professionals pragmatically selected more willing or engaged patients to participate  
38 in the trials. However, in real-world clinical settings it is likely (and appropriate) that participants are  
39 provided with options regarding their follow-up care. The observer or Hawthorne effect<sup>71</sup> may be at  
40 play with participants potentially acting differently due to a belief that they are being watched. Such  
41 an effect may reduce with time, and some trial lengths may have been too short for this effect to  
42 wear off.

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46 Our review was strengthened by a comprehensive search and inclusivity of diverse RPM  
47 interventions across a broad spectrum of conditions and contexts. The novel use of realist review  
48 methodology and development of theory-based constructs helped to systematically identify factors  
49 impacting upon implementation. However, while our focus was on acute care use, other aspects of  
50 care may have been overlooked that relate to care quality. Further, it is possible that reducing  
51 hospital admissions may shift care and associated costs to the primary care setting and potentially  
52 resulting in additional pressure and stress on different aspects of the system. Additionally, the  
53 theories that have been developed are based on both our and the primary study authors'  
54 interpretation of findings in many instances and not experimental evidence. Future studies should  
55 investigate any unintended consequences of RPM and cost implications resulting from the shifting of  
56 care.

## Conclusion

RPM interventions have the potential to reduce acute care use when they are targeted to appropriate populations and disease states, designed well, and implemented with patients and providers in mind. This review has highlighted important considerations for developing effective RPM devices, systems and revised models of care. To achieve significant changes in acute care use, RPM data needs to be routinely entered and checked, automated where possible, alerts need to accurately highlight when a person's data is beyond an acceptable range (for that person), and healthcare staff need to respond in a timely and appropriate manner. Further, information and feedback needs be provided to patients in a way that empowers them to self-manage their condition. If designed with these considerations in mind, RPM interventions are more likely to be effective at reduce acute care use.

## List of abbreviations

COPD: chronic obstructive pulmonary disease; CMO: context-mechanism-outcome; PROSPERO: Prospective Register of Systematic Reviews; RAMESES: Realist and Meta-narrative Evidence Synthesis: Evolving Standards; RPM: Remote patient monitoring.

## Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: All authors consent to publication

Availability of data and materials: Not applicable

Competing interests: None to declare

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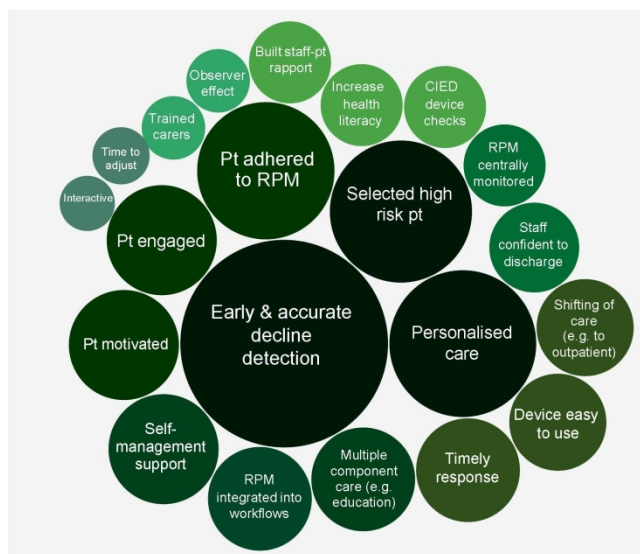


Figure 1 Factors associated with RPM intervention studies that reduced acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring

364x215mm (192 x 192 DPI)

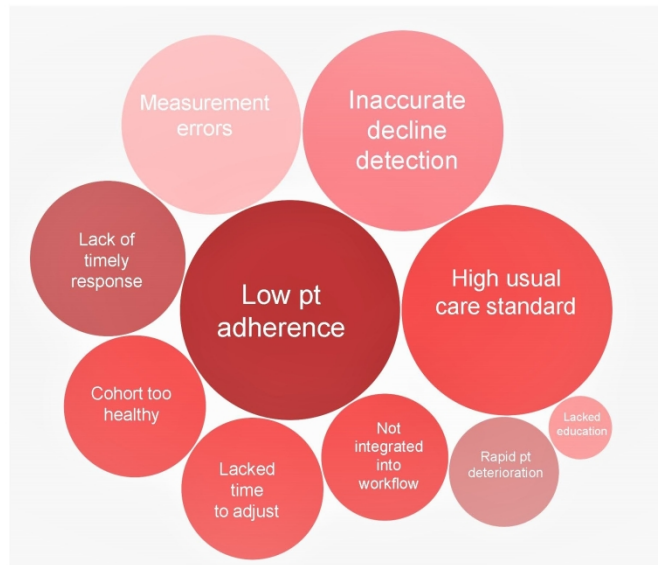


Figure 2 Factors associated with RPM interventions studies that increased acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

RPM: remote patient monitoring; Pt: patient

728x431mm (96 x 96 DPI)

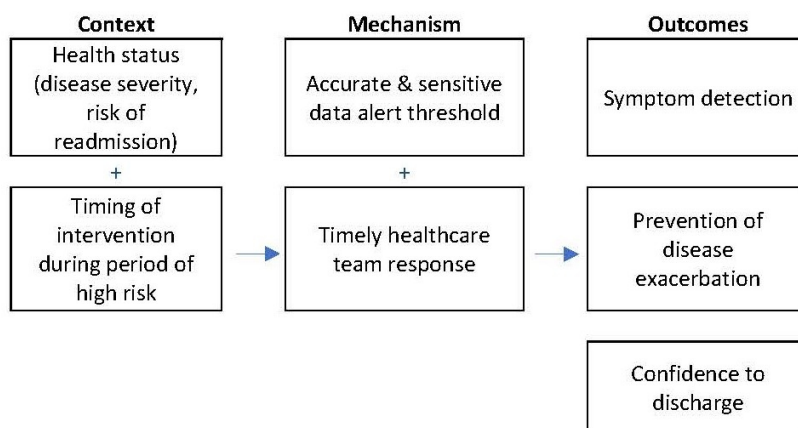


Figure 3. Proposed context-mechanism-outcome: target population

310x171mm (96 x 96 DPI)

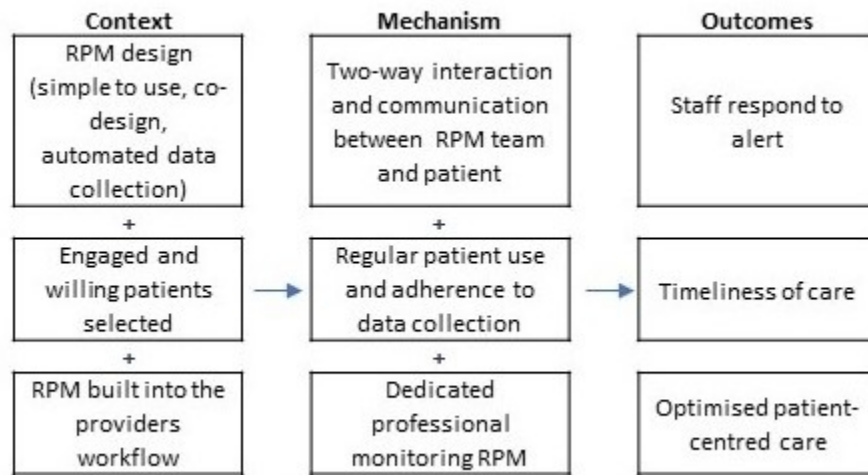


Figure 4. Proposed context-mechanism-outcome: timely care

121x72mm (96 x 96 DPI)

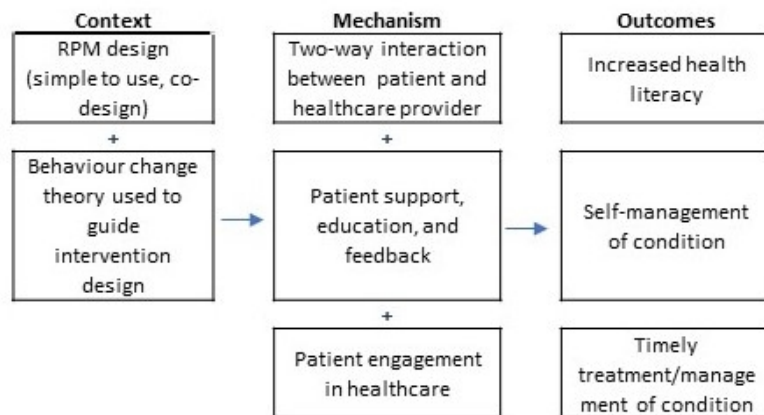


Figure 5. Proposed context-mechanism-outcome: self-management

150x87mm (96 x 96 DPI)



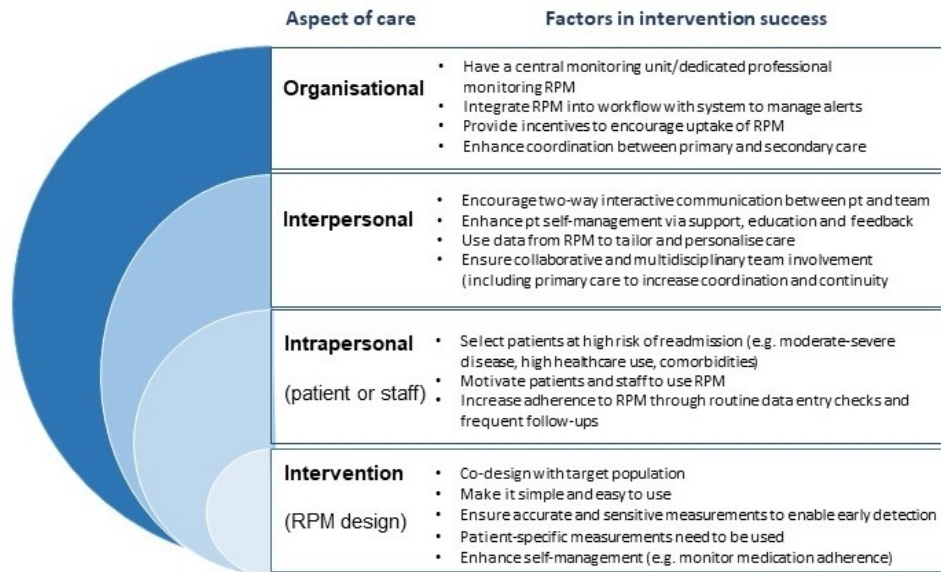


Figure 6. Recommendations to enhance RPM and reduce acute care use

192x128mm (96 x 96 DPI)

## Appendix A

### RAMESES publication standards: realist synthesis

Wong, G., Greenhalgh, T., Westhorp, G. *et al.* RAMESES publication standards: realist syntheses. *BMC Med* **11**, 21 (2013).

<https://doi.org/10.1186/1741-7015-11-21>

TITLE			Pg No.
1		In the title, identify the document as a realist synthesis or review	1
ABSTRACT			
2		While acknowledging publication requirements and house style, abstracts should ideally contain brief details of: the study's background, review question or objectives; search strategy; methods of selection, appraisal, analysis and synthesis of sources; main results; and implications for practice.	2
INTRODUCTION			
3	Rationale for review	Explain why the review is needed and what it is likely to contribute to existing understanding of the topic area.	3
4	Objectives and focus of review	State the objective(s) of the review and/or the review question(s). Define and provide a rationale for the focus of the review.	3
METHODS			
5	Changes in the review process	Any changes made to the review process that was initially planned should be briefly described and justified.	N/A

TITLE			Pg No.
6	Rationale for using realist synthesis	Explain why realist synthesis was considered the most appropriate method to use.	4
7	Scoping the literature	Describe and justify the initial process of exploratory scoping of the literature.	4
8	Searching processes	While considering specific requirements of the journal or other publication outlet, state and provide a rationale for how the iterative searching was done. Provide details on all the sources accessed for information in the review. Where searching in electronic databases has taken place, the details should include, for example, name of database, search terms, dates of coverage and date last searched. If individuals familiar with the relevant literature and/or topic area were contacted, indicate how they were identified and selected.	4
9	Selection and appraisal of documents	Explain how judgements were made about including and excluding data from documents, and justify these.	4. also additional details provided in previously published paper
10	Data extraction	Describe and explain which data or information were extracted from the included documents and justify this selection.	As above
11	Analysis and synthesis processes	Describe the analysis and synthesis processes in detail. This section should include information on the constructs analyzed and describe the analytic process.	As above
RESULTS			
12	Document flow diagram	Provide details on the number of documents assessed for eligibility and included in the review with reasons for exclusion at each stage as well as an indication of their source of origin (for example, from searching databases, reference lists and so on). You may consider	This paper included articles from a previously published review that followed the PRISMA guidelines – the flow

TITLE			Pg No.
		using the example templates (which are likely to need modification to suit the data) that are provided.	diagram is published within that paper.
13	Document characteristics	Provide information on the characteristics of the documents included in the review.	4-8
14	Main findings	Present the key findings with a specific focus on theory building and testing.	4-8
DISCUSSION			
15	Summary of findings	Summarize the main findings, taking into account the review's objective(s), research question(s), focus and intended audience(s).	9
16	Strengths, limitations and future research directions	Discuss both the strengths of the review and its limitations. These should include (but need not be restricted to) (a) consideration of all the steps in the review process and (b) comment on the overall strength of evidence supporting the explanatory insights which emerged. The limitations identified may point to areas where further work is needed.	10
17	Comparison with existing literature	Where applicable, compare and contrast the review's findings with the existing literature (for example, other reviews) on the same topic.	9-10
18	Conclusion and recommendations	List the main implications of the findings and place these in the context of other relevant literature. If appropriate, offer recommendations for policy and practice.	10/11
19	Funding	Provide details of funding source (if any) for the review, the role played by the funder (if any) and any conflicts of interests of the reviewers.	1

# BMJ Open

## Factors influencing effectiveness of remote patient monitoring interventions: A realist review

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# 1 Factors influencing effectiveness of remote patient monitoring 2 interventions: A realist review

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## 37 **Abstract** (258 words)

38

39 *Objectives:* Our recent systematic review determined that remote patient monitoring (RPM)  
40 interventions can reduce acute care use. However, effectiveness varied within and between  
41 populations. Clinicians, researchers, and policymakers require more than evidence of effect; they  
42 need guidance on how best to design RPM interventions. Therefore, this study aimed to explore  
43 these results further to (1) identify factors of RPM interventions that relate to increased and  
44 decreased acute care use, and (2) develop recommendations for future RPM intervention design and  
45 implementation.

46 *Design:* Realist review - a qualitative systematic review method which aims to identify and explain  
47 why intervention results vary in different situations. We analysed secondarily the ninety-one studies  
48 included in our previous systematic review that reported on RPM interventions and the impact on  
49 acute care use. Included studies were published between 2015-2020.

50 *Primary and secondary outcome measures:* Contextual factors and potential mechanisms that led to  
51 variation in acute care use (hospitalisations, length of stay, or emergency department  
52 presentations).

53 *Results:* We found that across a broad range of RPM interventions 31 factors emerged that are likely  
54 to impact the effectiveness of RPM innovations on acute care use. These were synthesised into six  
55 theories of intervention success: 1) targeting populations at high risk; 2) accurately detecting a  
56 decline in health; 3) providing responsive and timely care; 4) personalising care; 5) enhancing self-  
57 management and, 6) ensuring collaborative and coordinated care.

58 *Conclusion:* While RPM interventions are complex, if they are designed with patients, providers and  
59 the implementation setting in mind and with the key variables identified within this review  
60 incorporated, it is more likely that they will be effective at reducing acute hospital events.

61 *Registration:* The protocol for our review was registered (#CRD42020142523) with the Prospective  
62 Register of Systematic Reviews (PROSPERO).

63

## 64 **Strengths and limitations**

- 65 • Our review was strengthened by a comprehensive search and inclusivity of diverse RPM  
66 interventions across a broad spectrum of conditions and contexts.
- 67 • The novel use of realist review methodology and development of theory-based constructs  
68 helped to systematically identify factors impacting upon implementation.
- 69 • Included studies within our review had multiple study design issues. Typically, with many of  
70 these studies it is not possible (or ethical) to blind participants. Therefore, selection bias may  
71 have effected results if health professionals pragmatically selected more willing or engaged  
72 patients to participate in the trials.
- 73 • While our focus was on acute care use, other aspects of care may have been overlooked that  
74 relate to care quality.



## 75 Introduction

76  
77 Non-communicable diseases such as heart disease, chronic obstructive pulmonary disease (COPD),  
78 and diabetes accounts for over 70 per cent of global deaths each year.<sup>1</sup> Combined with the added  
79 challenge of ageing populations, health systems internationally are under enormous strain to  
80 support growing numbers of chronically unwell people.<sup>2</sup> One of the main drivers of healthcare costs  
81 for chronically ill patients results from acute hospital admissions due to their intense resource  
82 requirements. Consequently, new models of care are being widely investigated and trialled that  
83 could extend care into the home and prevent unnecessary acute care events.

84  
85 Remote patient monitoring (RPM) is a telehealth innovation that offers significant opportunities to  
86 increase the timeliness of care, enhance health outcomes, and potentially reduce hospitalisations  
87 and associated healthcare costs.<sup>3,4</sup> RPM uses technology to observe a patient's physiological (e.g.  
88 heart rate, blood pressure) and behavioural (e.g. medication adherence, physical activity)  
89 information from a distance.<sup>5</sup> With support, many individuals could effectively self-manage chronic  
90 conditions in the community.<sup>6</sup> Further, if alerted early, healthcare providers could intervene when a  
91 person's health is declining, potentially preventing costly escalations to hospital. Health  
92 professionals can routinely monitor a patient's health data and/or be alerted when measurements  
93 exceed a pre-determined threshold. This allows for early intervention and ideally prevention of  
94 further exacerbation of a condition. RPM can benefit people with chronic illness as well as other  
95 population groups that benefit from continuous monitoring such as the frail and elderly, neonates or  
96 post-surgical patients.<sup>5</sup>

97  
98 Despite the potential benefits of RPM, investigations into its clinical and cost effectiveness have  
99 provided mixed results to date. For example, the impact of RPM on the heart failure population has  
100 resulted in multiple systematic reviews<sup>7</sup>, meta-analyses<sup>8,9</sup>, and reviews of reviews.<sup>10,11</sup> These  
101 reviews are generally positive about the potential benefits for patients and health services from RPM  
102 services,<sup>7,8,10,12</sup> but others also report limited or no effect<sup>9</sup> on reducing morbidity and mortality. A  
103 2018 Cochrane review reported no difference in all-cause mortality in remotely monitored patients  
104 with heart failure and a change in hospitalisations ranging from a 64% decrease to a 60% increase.<sup>9</sup>

105  
106 In our recent review<sup>13</sup>, we provided a synthesis of the available evidence for the effect of RPM on  
107 acute care use including hospital admission events, hospital length of stay, and emergency  
108 department presentations. We found that RPM was reported to reduce acute care use in  
109 approximately 45% of studies. Remaining studies largely reported no change; however, some  
110 reported an increase in acute care use. The included 91 studies covered multiple chronic conditions,  
111 countries and health care organisations and used various technology and models of care. While RPM  
112 can have a positive impact on reducing acute care use, certain enablers are needed. Clinicians,  
113 researchers, and policymakers require more guidance on how to design and implement RPM-  
114 facilitated models of care to achieve the greatest benefit. Consequently, further analysis is required  
115 to understand underlying mechanisms causing such variation in acute care use across RPM  
116 interventions.

117  
118 We sought to understand what causes variation in outcomes from RPM interventions. Realist review  
119 methodology enables exploration of how, why and for whom interventions do and do not work.  
120 Consequently, the approach has been used across various health interventions (e.g. medical  
121 education programs<sup>14</sup>, school feeding programs<sup>15</sup>). The basic tenant of realist philosophy is that the  
122 effectiveness of an intervention is impacted by the context in which it is implemented which will  
123 trigger mechanisms that result in intended and unintended outcomes.<sup>16</sup> Realist reviews are  
124 particularly helpful for complex interventions like RPM interventions where the effectiveness is

1  
2  
3 125 impacted by multiple interacting components such as the intervention design, users, interpersonal  
4 126 relationships and institutions and settings where the intervention is delivered.

5 127

6 128 Specifically, this study aims to (1) identify factors of RPM interventions that relate to increased and  
7 129 decreased acute care use, and (2) develop recommendations for future RPM intervention design and  
8 130 implementation.

## 11 131 **Methods**

### 13 132 **Data extraction**

14 133 We used data from our recent systematic review<sup>13</sup> that compared acute care use between  
15 134 individuals who were and were not monitored using RPM. Complete details of the original  
16 135 systematic review have been described elsewhere.<sup>13</sup> In brief, search terms for remote monitoring  
17 136 and acute care utilisation were used across three electronic databases: PubMed (MEDLINE)[1966-  
18 137 2020], EMBASE (OvidSP)[1974-2020], and CINAHL (EBSCOHost)[1982-2020]. The search, conducted  
19 138 in October 2020, included articles published in the last five years (2015-2020). Articles were included  
20 139 if they used RPM to monitor an individual's biometrics (e.g. heart rate, blood pressure) from a  
21 140 distance while they are not in hospital. No restrictions were placed on patient age, or disease  
22 141 conditions however full-text studies had to be available in English.

23 142

24 143 We then re-reviewed the same 91 articles included in our original RPM systematic review, using  
25 144 realist review methodology to identify factors that determine intervention success and failure in  
26 145 various contexts. This review was guided by the work of Pawson et al (2005)<sup>17</sup> and followed  
27 146 guidelines outlined by the Realist and Meta-narrative Evidence Synthesis: Evolving Standards  
28 147 (RAMESES; Appendix A)<sup>18</sup>. According to the methodology described by Pawson et. al.<sup>17</sup> information  
29 148 was extracted that related to context (settings, populations, intervention delivery); outcomes  
30 149 (positive, negative or null effect on outcome of hospital use), and potential mechanisms or reasons  
31 150 behind the results (e.g. author's interpretation as to why the interventions did or did not work).  
32 151 These data were recorded in an Excel spreadsheet to facilitate a structured analysis. Two researchers  
33 152 (ET, MT) independently extracted these data.

34 153

### 38 154 **Evidence synthesis**

39 155 The researchers then collectively examined the articles to detect patterns and developed a  
40 156 compendium of explanatory factors observed in the RPM studies. The researchers compared and  
41 157 discussed their identified factors that led to increased or decreased acute care use being reported in  
42 158 the studies. Findings were then combined into a table showing the number of studies proposing  
43 159 each mechanism and grouped by outcome (e.g. increased or decreased acute care use).

44 160

45 161 The two researchers then jointly mapped recurrent patterns into explanatory context-mechanism-  
46 162 outcome (CMO) diagrams to illustrate how the different factors interact. Literature was also  
47 163 examined for opposing or conflicting viewpoints. These CMO diagrams were discussed with a third  
48 164 member of the research team (LC) to confirm consistent and logical development. Key findings were  
49 165 synthesised into overarching themes, which are referred to as 'theories' in the realist review  
50 166 approach.<sup>17</sup> Finally, a list of recommendations were developed from the findings and ordered by  
51 167 context to guide future RPM intervention design and implementation.

52 168

### 55 169 **Patient and public involvement**

56 170 Patients or the public were not involved in the design, or conduct, or reporting, or dissemination  
57 171 plans of our research.

58 172

## 173 Results

174 Ninety-one articles from our previous review were evaluated to determine why RPM increased,  
175 decreased, or had no effect on acute care use. Thirty-one factors were identified and mapped onto  
176 two outcomes: 1) increased hospital use (21 factors) and 2) reduced hospital use (10 factors)  
177 (Figures 1 & 2). Factors were also ordered by the frequency of articles that reported them as  
178 possible influences on outcomes (represented by the size of each factor in Figure 1 and 2).

### 180 [Insert Figure 1]

181 **Figure 1** Factors associated with RPM intervention studies that reduced acute care use.

182 *The size of each box relates to the number of studies that identified each factor as having an important*  
183 *influence on the outcome.*

184 *CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring*

### 186 [Insert Figure 2]

187 **Figure 2** Factors associated with RPM interventions studies that increased acute care use.

188 *The size of each box relates to the number of studies that identified each factor as having an important*  
189 *influence on the outcome.*

190 *RPM: remote patient monitoring; Pt: patient*

## 192 Theories about how RPM works

193 It was identified that successful RPM interventions, in this case those interventions that successfully  
194 reduced acute care use, were those that: 1) *target populations at high risk*; 2) *accurately detect a*  
195 *decline in health*; 3) *were responsive and provided timely care*; 4) *provided personalised care*; 5)  
196 *enhanced self-management* and, 6) *ensured collaborative and coordinated care*. Each of these  
197 theories of intervention success are described below.

### 199 Target populations at high risk

200 Appropriate selection of patients for RPM is crucial if a change in acute care use is to be achieved.  
201 RPM interventions are likely to have more pronounced effects on acute care use when they are  
202 targeted towards populations with a high risk of hospitalisation (e.g. moderate-severe disease  
203 severity, multiple comorbidities).<sup>19</sup> Further, it is important for the intervention to be timed with  
204 periods of high-risk readmissions (e.g. the first 90 days post an index event). Delaying the delivering  
205 of RPM devices to patients may reduce the effect<sup>20</sup> (See Figure 3).

206 Patients who are more likely to present to hospital multiple times have a greater chance of reducing  
207 admissions due to more timely interventions. In practice, however, clinicians may have reservations  
208 about remotely assessing their most vulnerable and unwell patients. As described by Geller et al.,<sup>21</sup>  
209 *“in clinical practice telemedicine seems to be used mainly in patients with better prognosis, probably*  
210 *due to the belief that those who live longer may receive more (i.e. prolonged) benefit from*

1  
2  
3 211 *telemonitoring than sicker patients who should be seen in the office more frequently” (pg. 1124).*  
4 212 Consequently, clinicians may require additional information on how RPM can be safely delivered in  
5 213 high-risk cohorts.  
6  
7

8 214

9  
10 215 **[Insert Figure 3]**

11 216 *Figure 3. Proposed context-mechanism-outcome: target population*

12  
13 217

14  
15 218 ***Accurately detect a decline in health***

16  
17 219 RPM needs to accurately predict disease exacerbations by detecting a change in symptoms that  
18 220 relate to health deteriorations. This has been a challenge in certain populations such as COPD and  
19 221 heart failure patients which may have unpredictable disease progression. In the COPD population,  
20 222 multiple studies reported trying to determine the measurement (e.g. spirometry, oximetry, or a  
21 223 combination) which would mark the onset of an exacerbation,<sup>22-25</sup> however, none came to a  
22 224 definitive conclusion.<sup>26</sup> RPM can be used in these population groups to longitudinally track the  
23 225 progression of disease and develop parameters to be tested as predictors for future interventions.<sup>27</sup>

24  
25  
26 226 In the heart failure population, physiological signs may not provide adequate warning of  
27 227 decompensation. Readmission in this cohort can be a complex interplay of multiple factors and is  
28 228 often not solely limited to physiological variables.<sup>28</sup> If deterioration occurs too quickly, there is  
29 229 limited opportunity to intervene.<sup>29</sup> Therefore, more investigation is required to try and accurately  
30 230 predict health declines for individual patients and accurately pin-point the best way for RPM to be  
31 231 used to support this patient population.

32  
33 232 Implantable devices (e.g. pacemakers) have an additional advantage; continuous monitoring enables  
34 233 undiagnosed co-morbid conditions such as atrial fibrillation to be detected enabling pre-emptive  
35 234 intervention.<sup>30</sup> It can also improve the efficiency of outpatient clinical care by detecting device or  
36 235 lead malfunctions earlier.<sup>31</sup>

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43 237 ***Provide timely care via a responsive system***

44  
45 238 Any benefit from RPM is dependent on patients 1) using the system (e.g. timely data entry) and, 2)  
46 239 providers taking appropriate and equally timely action when out-of-range readings occur.<sup>30</sup>  
47 240 Therefore, RPM systems that use automated data entry wherever possible are preferable as they  
48 241 can reduce errors and delays due to manual entry. As technology improves, smartphone-based  
49 242 programs are likely to replace standard RPM equipment which may result in more consistent,  
50 243 accurate and timely data from patients.<sup>19</sup> For innovations that rely on manual data entry, RPM  
51 244 innovations need to be easy to use (e.g. enables efficient data entry, transportable) and useful for  
52 245 patients to ensure long term use and engagement.<sup>32</sup> Additionally, regular monitoring is required. For  
53 246 example, Srivastava et al.<sup>19</sup> routinely monitored data for abnormalities or lack of responses; if a  
54 247 patient did not submit data for three days, a call was initiated by nursing staff.

55  
56  
57 248 On the staff end, RPM alerts need to be actioned with timely and appropriate responses; the speed  
58 249 of decision-making and frequency of monitoring is paramount.<sup>33</sup> A fast response often requires  
59 250 frequent contact with patients and effective bi-directional communication pathways between staff

1  
2  
3 251 and patients. For example, Trucco et al.<sup>34</sup> facilitated communication between families and the on-  
4 252 call team via a dedicated phone number or email address. Multiple studies report the importance of  
5 253 dedicated care (e.g. providing an RPM nurse or dedicated case manager) in improving response  
6 254 time.<sup>33, 35-38</sup> This is supported by the literature with findings that patients who received either basic  
7 255 or intensive case management spend less time in hospital than those without.<sup>39</sup> “Fast tracked”  
8 256 access to primary care providers was used in the intervention reported by Pedone et al.<sup>40</sup> when  
9 257 abnormalities were presented, or new symptoms arose. They reported that a new model of care,  
10 258 rather than simply implementing a new technology, was required to obtain sizable benefits in terms  
11 259 of hospitalisation outcomes.<sup>40</sup> Where possible, RPM should be embedded into the system and  
12 260 provide seamless interaction between patients and the healthcare system with minimal  
13 261 encumbrance on both ends.<sup>19</sup> The proposed context-mechanism-outcome diagram is provided in  
14 262 Figure 4.

15 263  
16 264 **[Insert Figure 4]**

17 265 *Figure 4. Proposed context-mechanism-outcome: timely care*

#### 18 266 19 267 **Provide personalised care**

20 268 Providing a patient-centric and personalised approach was also an important factor in determining  
21 269 the success of an RPM intervention in reducing acute care use.<sup>19</sup> Firstly, the development of the RPM  
22 270 innovation needs to be co-designed with patients and their families to ensure it meets their needs  
23 271 and maximise acceptance and uptake.<sup>41</sup> Training patients on how to use the device will likely also  
24 272 need to be personalised and at times repeated. RPM alerts can also be personalised by using  
25 273 individual data to determine alert thresholds. Koelher et al.<sup>42</sup> recommended defining a risk category  
26 274 for each individual patient based on their positive results (derived from biometric data). One study  
27 275 author requested personalised parameters and treatment guidelines from each patient’s treating  
28 276 physician.<sup>43</sup> Determining appropriate parameters for RPM applications (personalised or not) enables  
29 277 the treating team to be alerted to any biometric measurements that fall outside of the personalised  
30 278 parameter ranges. To enable these personalised parameters to be developed physicians need to be  
31 279 engaged in the RPM process for their patient early. The response by the RPM monitoring team also  
32 280 needs to be tailored; considering the person’s medical, social and emotional needs.

#### 33 281 34 282 **Enhance self-management**

35 283 To successfully reduce acute care use, RPM interventions should include support and education to  
36 284 increase self-management skills. Through developing knowledge, skills and positive behaviours (e.g.  
37 285 medication adherence), patients are more likely to be able to effectively manage their condition  
38 286 with the aid of RPM (see Figure 5).<sup>44</sup> Additionally, increased awareness of signs and symptoms of  
39 287 disease progression that often occurs when patients use RPM can prompt them to contact their  
40 288 healthcare provider for timely management.<sup>44</sup> Providing feedback from RPM data in a way that  
41 289 empowers patients to take control of their own health is important. Koelher et al.<sup>42</sup> reported that  
42 290 this needs to be a comprehensive approach including education and patient involvement when  
43 291 developing management strategies. In some instances, RPM interventions were discontinued once  
44 292 patients were able to correctly correlate their personal symptoms and seek help when required.<sup>43</sup>

1  
2  
3 293 Conversely, some RPM interventions that were unsuccessful in reducing hospitalisation events  
4 294 reported patients becoming overly reliant on the RPM team, for instance alerting the team know  
5 295 when an issue arose rather than developing autonomous self-management skills for their condition.  
6 296 Additionally, some known important factors such as medication adherence were not always  
7 297 measured and present a lost opportunity in many RPM innovations. Medication adherence and  
8 298 timely changes to medications are reported to confer substantial benefits for patients.<sup>42</sup>

11 299 **[Insert Figure 5]**

13 300

15 301 *Figure 5. Proposed context-mechanism-outcome: self-management*

17 302

### 19 303 **Ensure collaborative and coordinated care**

21 304 Successful RPM studies demonstrated increased connection and communication between  
22 305 healthcare staff and patients.<sup>31</sup> Multidisciplinary team-based interventions that combine feedback  
23 306 (automated and/or provider-initiated) with other approaches (e.g. coaching, motivational  
24 307 interviews, and shared decision-making) are more likely to result in improvement in adherence.<sup>45</sup>  
25 308 Involvement of primary care is crucial. As high-risk patients are often managed by primary and  
26 309 specialty care, both hospital and primary care settings should be involved in RPM interventions.<sup>46</sup>  
27 310 Involvement of key stakeholders is required to improve continuity of care.<sup>47</sup> Beyond healthcare  
28 311 professionals, the RPM intervention should also aim to include families and carers as key  
29 312 stakeholders in the long-term management of the person's condition. To increase primary carers'  
30 313 acceptance of and adherence to RPM, they must be involved very early on. To institute an initial  
31 314 change of role, staff incentives (e.g. financial payments) may be required.<sup>27</sup> Additionally, nursing  
32 315 staff should be considered as having leading roles in RPM interventions.<sup>48</sup> Further, institutional  
33 316 support is required for these initiatives and reorganisation of care processes should be carefully  
34 317 planned and implemented.<sup>48</sup>

### 40 318 **Factors that resulted in increased acute care use**

42 319 A range of factors were identified as having a negative influence on hospital use (increasing  
43 320 admissions) (Figure 2). Many of the identified factors are the reverse of what has been described  
44 321 above. For example, not targeting populations at high risk, not integrating RPM into the workflow or  
45 322 using systems that have measurement errors. For example, multiple study authors reported slow  
46 323 alert response times (N=6)<sup>32, 49-53</sup> and low patient or clinician adherence (N=11)<sup>19, 20, 28, 32, 45, 54-59</sup> as  
47 324 important factors resulting in no change or an increase in acute care use in the RPM group. There  
48 325 also appears to be a delicate balance between providing a supportive environment that empowers  
49 326 patients to self-manage versus having patients become reliant on the RPM device and/or the  
50 327 monitoring team.

53 328

### 55 329 **Recommendations for RPM**

57 330 We synthesised multiple recommendations to assist in the design and implementation of RPM  
58 331 interventions (Figure 6).

332 When designing RPM devices, it is crucial that the measured biometrics accurately predict disease  
333 exacerbations. Alert thresholds need to be carefully determined to ensure they are sensitive to  
334 physiological changes without being too high, and where possible tailored to the patient and disease  
335 state. Further, the transmission of data needs to be reliable, and if possible, automatic.

336 It is essential that RPM devices are co-designed with consumers and providers to improve usability  
337 and engagement with the RPM system. It is likely that making the device interactive and building in  
338 feedback loops between the patient and clinician will enhance engagement. However, if this  
339 increases the provider's workload it may discourage provider engagement. Multidisciplinary team  
340 interventions that combine feedback with other approaches like patient education, motivational  
341 interviewing, coaching or shared decision-making are likely to be more effective long-term.<sup>60</sup>

342 At the organisation level, having dedicated professionals responsible for monitoring data and  
343 communicating with patients and the healthcare team can improve the timeliness and coordination  
344 of care. Studies with nursing staff in these leading and case-management roles appeared to be more  
345 effective.<sup>48</sup> RPM also needs to be embedded into the health system to provide seamless interaction  
346 between patients and the healthcare system. This may require reorganisation of care and additional  
347 resources (physical and personnel) to support the intervention.

348

349 **[Insert Figure 6]**

350 *Figure 6. Recommendations to enhance RPM and reduce acute care use*

351

## 352 Discussion

353 We found that RPM interventions were successful at reducing acute care use when they  
354 incorporated a number of elements including; accurately predicting a decline in health or disease  
355 exacerbation, timely response to alerts, personalised patient parameters, and a focus on enhancing  
356 patient self-management. Additionally, RPM needed to improve the continuity of care by enhancing  
357 collaboration between specialists and primary care. To the best of our knowledge, this is the first  
358 review to elucidate why some RPM interventions are more successful than others in reducing acute  
359 care use.

360 RPM interventions are complex because they typically involving multiple components (e.g. data  
361 collection, education, feedback) and various stakeholders across different settings (e.g. community,  
362 primary and tertiary care). Given the complexity of RPM interventions, it is perhaps unsurprising that  
363 RPM studies have resulted in so much variation in the effects demonstrated regarding changes in  
364 acute care use. To date, much of the focus of RPM innovations has been on the design and  
365 development of the technology.<sup>61, 62</sup> While functioning technology that accurately detects a decline in  
366 health is important, to deliver significant benefits RPM alerts must also lead to an actionable and  
367 timely responses. To achieve positive results at the healthcare system level, RPM interventions  
368 require a change to the *model of care* rather than simple technology implementation.<sup>63</sup>

369 To be successful, the right patients need to be recruited at the right time. Patients with greater  
370 disease severity and at high risk of readmissions appear to confer the greatest benefit of RPM  
371 interventions in terms of reduced acute care use.<sup>64</sup> For instance, a recent consensus statement from  
372 the Heart Failure Society of America<sup>65</sup> broadly concluded that heart failure RPM had the most impact

373 when patients were most at risk (e.g., recent hospitalisation, prone to fluid overload, and struggles  
374 with medication adherence). Additionally, RPM should target patients who are willing and likely to  
375 adhere with RPM regimes.

376 While our study focuses on acute hospital use, other authors have investigated patient-related  
377 factors that may support long-term monitoring of conditions. For example, Huygens suggests there  
378 is a relationship between perceived disease controllability and patients' willingness to self-monitor.<sup>66</sup>  
379 Patients with diabetes, asthma and hypertension were most willing to self-monitor. In contrast,  
380 patients with rheumatism, migraines and other neurological disorders were less willing. The  
381 intervention design can facilitate engagement and use. Hong and Lee<sup>64</sup> determined that  
382 interventions with an educational component such as self-management programs have greater  
383 effects. Another consideration is the patient's social circumstance. One study found that RPM  
384 significantly improved outcomes for socially isolated patients,<sup>67</sup> potentially due to the delay in care  
385 access that these patients may face. Conversely, for socially connected patients, outcomes appear to  
386 be enhanced by training caregivers.<sup>29, 68</sup>

387 Interventions based on health behaviour models and personalised coaching were most successful.<sup>69</sup>  
388 The findings of this review parallel some of the themes in a review of patient experiences of RPM by  
389 Walker et al.<sup>70</sup> Similarly, self-management and early identification of clinical exacerbations were key  
390 to preventing hospitalisation. From the patient perspective, self-management was achieved by  
391 increasing confidence and providing a sense of safety. Shared decision making was identified as a  
392 key mechanism to preventing hospitalisation. Conversely, interventions that provided information  
393 but did not equip patients to self-manage were potentially at greater risk of having patients become  
394 overly reliant on the RPM team.

395 Patients have previously reported concerns about being lost in the data or losing interpersonal  
396 connections with health professionals and a reluctance to try something new, especially if unfamiliar  
397 with technology.<sup>70</sup> Our findings substantiate the importance of co-designing RPM interventions with  
398 consumers to ensure they are easy to use and provide useful feedback to maintain adherence and  
399 engagement. Building rapport, providing training (sometimes multiple times) and having a two-way  
400 interactive relationship between the patient and the RPM team is crucial. Alternatively, a lack of  
401 education and timely response were identified as factors that increased acute care use.

402 Included studies within our review had multiple study design issues. Typically, with many of these  
403 studies it is not possible (or ethical) to blind participants. Therefore, selection bias may have effected  
404 results if health professionals pragmatically selected more willing or engaged patients to participate  
405 in the trials. However, in real-world clinical settings it is likely (and appropriate) that participants are  
406 provided with options regarding their follow-up care. The observer or Hawthorne effect<sup>71</sup> may be at  
407 play with participants potentially acting differently due to a belief that they are being watched. Such  
408 an effect may reduce with time, and some trial lengths may have been too short for this effect to  
409 wear off. Potentially the higher number of studies reporting positive outcomes may be due to a  
410 reporting bias within the literature; consequently, there were a higher number of factors discussed  
411 in relation to reducing (n=21) rather than increasing acute care use (n=10).

412  
413 Our review was strengthened by a comprehensive search and inclusivity of diverse RPM  
414 interventions across a broad spectrum of conditions and contexts. The novel use of realist review  
415 methodology and development of theory-based constructs helped to systematically identify factors  
416 impacting upon implementation. However, while our focus was on acute care use, other aspects of  
417 care may have been overlooked that relate to care quality. Further, it is possible that reducing  
418 hospital admissions may shift care and associated costs to the primary care setting and potentially  
419 result in additional pressure and stress on different aspects of the system. Additionally, the theories



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3 420 that have been developed are based on both our and the primary study authors' interpretation of  
4 421 findings in many instances and not experimental evidence.  
5 422

## 8 423 **Conclusion**

10 424 RPM interventions have the potential to reduce acute care use when they are targeted to  
11 425 appropriate populations and disease states, designed well, and implemented with patients and  
12 426 providers in mind. This review has highlighted important considerations for developing effective  
13 427 RPM devices, systems and telehealth models of care. To achieve significant changes in acute care  
14 428 use, RPM data needs to be routinely entered and checked, automated where possible, alerts need to  
15 429 accurately highlight when a person's data is beyond an acceptable range (for that person), and  
16 430 healthcare staff need to respond in a timely and appropriate manner. Further, information and  
17 431 feedback needs be provided to patients in a way that empowers them to self-manage their  
18 432 condition. If designed with these considerations in mind, RPM interventions are more likely to be  
19 433 effective at reduce acute care use. Future studies should investigate any unintended consequences  
20 434 of RPM and cost implications resulting from the shifting of care.  
21 435

## 25 436 **List of abbreviations**

27 437 COPD: chronic obstructive pulmonary disease; CMO: context-mechanism-outcome; PROSPERO:  
28 438 Prospective Register of Systematic Reviews; RAMESES: Realist and Meta-narrative Evidence  
29 439 Synthesis: Evolving Standards; RPM: Remote patient monitoring.

## 32 440 **Declarations**

34 441 Ethics approval and consent to participate: Not applicable

35 442  
36 443 Consent for publication: All authors consent to publication

37 444  
38 445 Availability of data and materials: Not applicable

39 446  
40 447 Competing interests: None to declare

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45 452  
46 453 Authors' contributions: This research was conceptualised by ET. ET, LC, CS, MT contributed to the  
47 454 study design. Searches and data extraction were carried out by ET and MT with support from LC.  
48 455 Data analysis was performed by ET, MT and LC. Manuscript was drafted by ET, MT, AB and LC.  
49 456 Critical review of manuscript was undertaken by HH, CS, AS, VGR. All authors approved the final  
50 457 manuscript.

51 458 Acknowledgements: Not applicable

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For peer review only

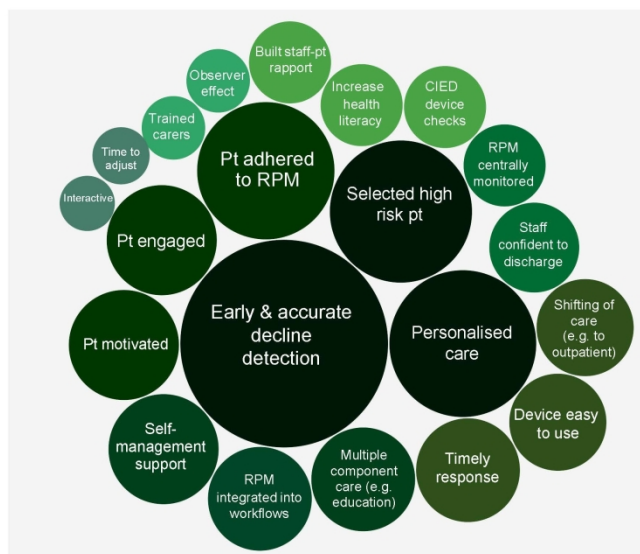


Figure 1 Factors associated with RPM intervention studies that reduced acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring

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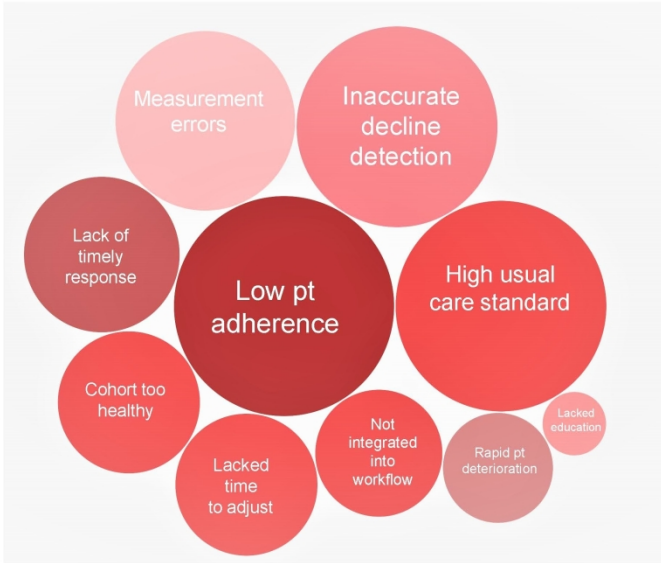


Figure 2 Factors associated with RPM interventions studies that increased acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

RPM: remote patient monitoring; Pt: patient

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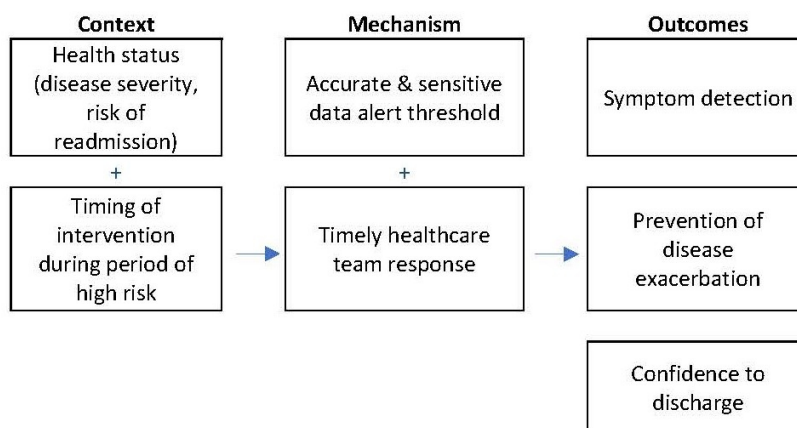


Figure 3. Proposed context-mechanism-outcome: target population

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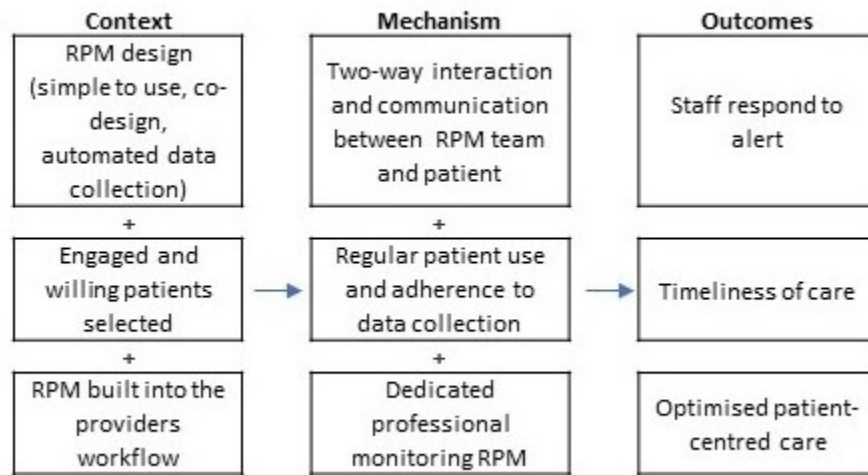


Figure 4. Proposed context-mechanism-outcome: timely care

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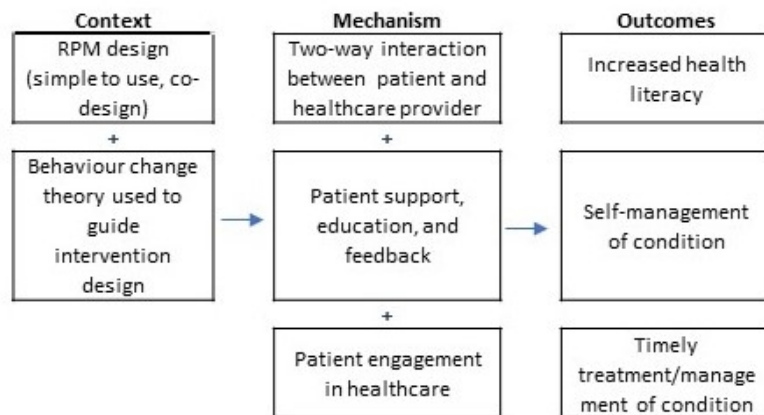


Figure 5. Proposed context-mechanism-outcome: self-management

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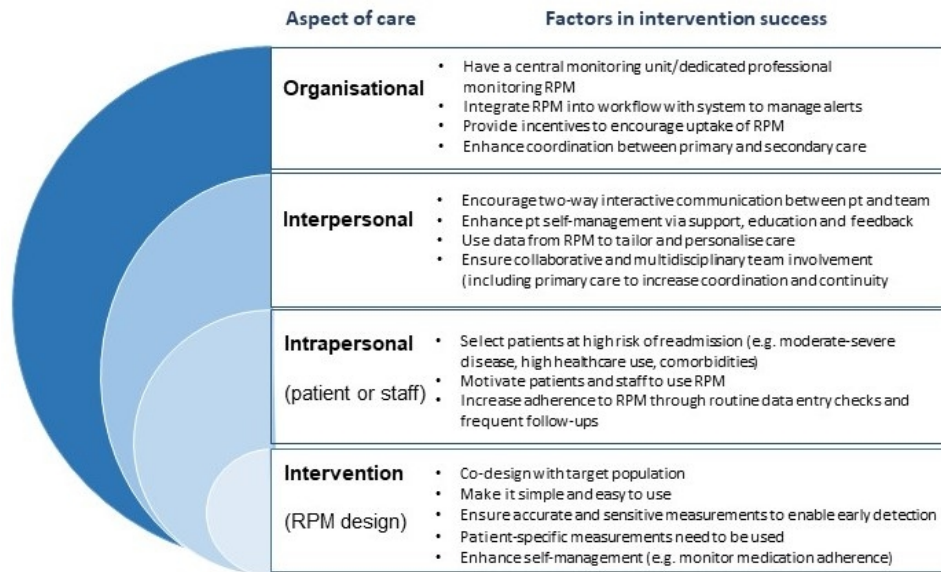


Figure 6. Recommendations to enhance RPM and reduce acute care use

192x128mm (96 x 96 DPI)

## Appendix A

### RAMESES publication standards: realist synthesis

Wong, G., Greenhalgh, T., Westhorp, G. *et al.* RAMESES publication standards: realist syntheses. *BMC Med* **11**, 21 (2013).

<https://doi.org/10.1186/1741-7015-11-21>

TITLE			Pg No.
1		In the title, identify the document as a realist synthesis or review	1
ABSTRACT			
2		While acknowledging publication requirements and house style, abstracts should ideally contain brief details of: the study's background, review question or objectives; search strategy; methods of selection, appraisal, analysis and synthesis of sources; main results; and implications for practice.	2
INTRODUCTION			
3	Rationale for review	Explain why the review is needed and what it is likely to contribute to existing understanding of the topic area.	3
4	Objectives and focus of review	State the objective(s) of the review and/or the review question(s). Define and provide a rationale for the focus of the review.	3
METHODS			
5	Changes in the review process	Any changes made to the review process that was initially planned should be briefly described and justified.	N/A

TITLE			Pg No.
6	Rationale for using realist synthesis	Explain why realist synthesis was considered the most appropriate method to use.	4
7	Scoping the literature	Describe and justify the initial process of exploratory scoping of the literature.	4
8	Searching processes	While considering specific requirements of the journal or other publication outlet, state and provide a rationale for how the iterative searching was done. Provide details on all the sources accessed for information in the review. Where searching in electronic databases has taken place, the details should include, for example, name of database, search terms, dates of coverage and date last searched. If individuals familiar with the relevant literature and/or topic area were contacted, indicate how they were identified and selected.	4
9	Selection and appraisal of documents	Explain how judgements were made about including and excluding data from documents, and justify these.	4. also additional details provided in previously published paper
10	Data extraction	Describe and explain which data or information were extracted from the included documents and justify this selection.	As above
11	Analysis and synthesis processes	Describe the analysis and synthesis processes in detail. This section should include information on the constructs analyzed and describe the analytic process.	As above
RESULTS			
12	Document flow diagram	Provide details on the number of documents assessed for eligibility and included in the review with reasons for exclusion at each stage as well as an indication of their source of origin (for example, from searching databases, reference lists and so on). You may consider	This paper included articles from a previously published review that followed the PRISMA guidelines – the flow

TITLE			Pg No.
		using the example templates (which are likely to need modification to suit the data) that are provided.	diagram is published within that paper.
13	Document characteristics	Provide information on the characteristics of the documents included in the review.	4-8
14	Main findings	Present the key findings with a specific focus on theory building and testing.	4-8
DISCUSSION			
15	Summary of findings	Summarize the main findings, taking into account the review's objective(s), research question(s), focus and intended audience(s).	9
16	Strengths, limitations and future research directions	Discuss both the strengths of the review and its limitations. These should include (but need not be restricted to) (a) consideration of all the steps in the review process and (b) comment on the overall strength of evidence supporting the explanatory insights which emerged. The limitations identified may point to areas where further work is needed.	10
17	Comparison with existing literature	Where applicable, compare and contrast the review's findings with the existing literature (for example, other reviews) on the same topic.	9-10
18	Conclusion and recommendations	List the main implications of the findings and place these in the context of other relevant literature. If appropriate, offer recommendations for policy and practice.	10/11
19	Funding	Provide details of funding source (if any) for the review, the role played by the funder (if any) and any conflicts of interests of the reviewers.	1

# BMJ Open

## Factors influencing effectiveness of remote patient monitoring interventions: A realist review

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# 1 Factors influencing effectiveness of remote patient monitoring 2 interventions: A realist review

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4  
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34 monitoring; hospitalization; length of stay; realist review

## 37 **Abstract** (300 words)

38

39 *Objectives:* Our recent systematic review determined that remote patient monitoring (RPM)  
40 interventions can reduce acute care use. However, effectiveness varied within and between  
41 populations. Clinicians, researchers, and policymakers require more than evidence of effect; they  
42 need guidance on how best to design and implement RPM interventions. Therefore, this study  
43 aimed to explore these results further to (1) identify factors of RPM interventions that relate to  
44 increased and decreased acute care use, and (2) develop recommendations for future RPM  
45 interventions.

46 *Design:* Realist review - a qualitative systematic review method which aims to identify and explain  
47 why intervention results vary in different situations. We analysed secondarily ninety-one studies  
48 included in our previous systematic review that reported on RPM interventions and the impact on  
49 acute care use. Online databases PubMed, EMBASE and CINAHL were searched in October 2020.  
50 Included studies were published in English during 2015-2020 and used RPM to monitor an  
51 individual's biometric data (e.g. heart rate, blood pressure) from a distance.

52 *Primary and secondary outcome measures:* Contextual factors and potential mechanisms that led to  
53 variation in acute care use (hospitalisations, length of stay, or emergency department  
54 presentations).

55 *Results:* Across a range of RPM interventions 31 factors emerged that impact the effectiveness of  
56 RPM innovations on acute care use. These were synthesised into six theories of intervention success:  
57 1) targeting populations at high risk; 2) accurately detecting a decline in health; 3) providing  
58 responsive and timely care; 4) personalising care; 5) enhancing self-management and, 6) ensuring  
59 collaborative and coordinated care.

60 *Conclusion:* While RPM interventions are complex, if they are designed with patients, providers and  
61 the implementation setting in mind and incorporate the key variables identified within this review ,  
62 it is more likely that they will be effective at reducing acute hospital events.

63 *Registration:* The review protocol was registered with PROSPERO (#CRD42020142523).

64

### 65 **Strengths and limitations**

- 66 • Our review was strengthened by a comprehensive search and inclusivity of diverse RPM  
67 interventions across a broad spectrum of conditions and contexts.
- 68 • The novel use of realist review methodology and development of theory-based constructs  
69 helped to systematically identify factors impacting implementation.
- 70 • Included studies within our review had multiple study design issues. Typically, with many of  
71 these studies it is not possible (or ethical) to blind participants. Therefore, selection bias may  
72 have affected results if health professionals pragmatically selected more willing or engaged  
73 patients to participate in the trials.
- 74 • While our focus was on acute care use, other aspects of care may have been overlooked that  
75 relate to care quality.

## 76 Introduction

77  
78 Non-communicable diseases such as heart disease, chronic obstructive pulmonary disease (COPD),  
79 and diabetes accounts for over 70 per cent of global deaths each year.<sup>1</sup> Combined with the added  
80 challenge of ageing populations, health systems internationally are under enormous strain to  
81 support growing numbers of chronically unwell people.<sup>2</sup> One of the main drivers of healthcare costs  
82 for chronically ill patients results from acute hospital admissions due to their intense resource  
83 requirements. Consequently, new models of care are being widely investigated and trialled that  
84 could extend care into the home and prevent unnecessary acute care events.

85  
86 Remote patient monitoring (RPM) is a telehealth innovation that offers significant opportunities to  
87 increase the timeliness of care, enhance health outcomes, and potentially reduce hospitalisations  
88 and associated healthcare costs.<sup>3,4</sup> RPM uses technology to observe a patient's physiological (e.g.  
89 heart rate, blood pressure) and behavioural (e.g. medication adherence, physical activity)  
90 information from a distance.<sup>5</sup> With support, many individuals could effectively self-manage chronic  
91 conditions in the community.<sup>6</sup> Further, if alerted early, healthcare providers could intervene when a  
92 person's health is declining, potentially preventing costly escalations to hospital. Health  
93 professionals can routinely monitor a patient's health data and/or be alerted when measurements  
94 exceed a pre-determined threshold. This allows for early intervention and ideally prevention of  
95 further exacerbation of a condition. RPM can benefit people with chronic illness as well as other  
96 population groups that benefit from continuous monitoring such as the frail and elderly, neonates or  
97 post-surgical patients.<sup>5</sup>

98  
99 Despite the potential benefits of RPM, investigations into its clinical and cost effectiveness have  
100 provided mixed results to date. For example, the impact of RPM on the heart failure population has  
101 resulted in multiple systematic reviews<sup>7</sup>, meta-analyses<sup>8,9</sup>, and reviews of reviews.<sup>10,11</sup> These  
102 reviews are generally positive about the potential benefits for patients and health services from RPM  
103 services,<sup>7,8,10,12</sup> but others also report limited or no effect<sup>9</sup> on reducing morbidity and mortality. A  
104 2018 Cochrane review reported no difference in all-cause mortality in remotely monitored patients  
105 with heart failure and a change in hospitalisations ranging from a 64% decrease to a 60% increase.<sup>9</sup>

106  
107 In our recent review<sup>13</sup>, we provided a synthesis of the available evidence for the effect of RPM on  
108 acute care use including hospital admission events, hospital length of stay, and emergency  
109 department presentations. We found that RPM was reported to reduce acute care use in  
110 approximately 45% of studies. Remaining studies largely reported no change; however, some  
111 reported an increase in acute care use. The included 91 studies covered multiple chronic conditions,  
112 countries and health care organisations and used various technology and models of care. While RPM  
113 can have a positive impact on reducing acute care use, certain enablers are needed. Clinicians,  
114 researchers, and policymakers require more guidance on how to design and implement RPM-  
115 facilitated models of care to achieve the greatest benefit. Consequently, further analysis is required  
116 to understand underlying mechanisms causing such variation in acute care use across RPM  
117 interventions.

118  
119 We sought to understand what causes variation in outcomes from RPM interventions. Realist review  
120 methodology enables exploration of how, why and for whom interventions do and do not work.  
121 Consequently, the approach has been used across various health interventions (e.g. medical  
122 education programs<sup>14</sup>, school feeding programs<sup>15</sup>). The basic tenet of realist philosophy is that the  
123 effectiveness of an intervention is impacted by the context in which it is implemented which may  
124 trigger mechanisms that result in intended and unintended outcomes.<sup>16</sup> Realist reviews are  
125 particularly helpful for complex interventions like RPM interventions where the effectiveness is

1  
2  
3 126 impacted by multiple interacting components such as the intervention design, users, interpersonal  
4 127 relationships and institutions and settings where the intervention is delivered.  
5 128

6 129 Specifically, this study aimed to (1) identify factors of RPM interventions that relate to increased and  
7 130 decreased acute care use, and (2) develop recommendations for future RPM intervention design and  
8 131 implementation.  
9

## 10 11 132 **Methods**

### 12 13 133 **Data extraction**

14 134 We used data from our recent systematic review<sup>13</sup> that compared acute care use between  
15 135 individuals who were and were not monitored using RPM. Complete details of the original  
16 136 systematic review have been described elsewhere.<sup>13</sup> In brief, search terms for remote monitoring  
17 137 and acute care utilisation were used across three electronic databases: PubMed (MEDLINE)[1966-  
18 138 2020], EMBASE (OvidSP)[1974-2020], and CINAHL (EBSCOHost)[1982-2020]. The search, conducted  
19 139 in October 2020, included articles published in the last five years (2015-2020). Articles were included  
20 140 if they used RPM to monitor an individual's biometrics (e.g. heart rate, blood pressure) from a  
21 141 distance while they are not in hospital. No restrictions were placed on patient age, or disease  
22 142 conditions however full-text studies had to be available in English.  
23 143

24 144 We then re-reviewed the same 91 articles included in our original RPM systematic review, using  
25 145 realist review methodology to identify factors that determine intervention success and failure in  
26 146 various contexts. This review was guided by the work of Pawson et al. (2005)<sup>17</sup> and followed  
27 147 guidelines outlined by the Realist and Meta-narrative Evidence Synthesis: Evolving Standards  
28 148 (RAMESES; Appendix A)<sup>18</sup>. Following the methodology described by Pawson et al.,<sup>17</sup> information  
29 149 was extracted that related to context (settings, populations, intervention delivery), outcomes  
30 150 (positive, negative or null affect on outcome of hospital use), and potential mechanisms or reasons  
31 151 behind the results (e.g. author's interpretation as to why the interventions did or did not work).  
32 152 These data were recorded in an Excel spreadsheet to facilitate a structured analysis. Two researchers  
33 153 (ET, MT) independently extracted these data.  
34 154

### 35 155 **Evidence synthesis**

36 156 The researchers then collectively examined the articles to detect patterns and developed a  
37 157 compendium of explanatory factors observed in the RPM studies. The researchers compared and  
38 158 discussed their identified factors that led to increased or decreased acute care use being reported in  
39 159 the studies. Findings were then combined into a table showing the number of studies proposing  
40 160 each mechanism and grouped by outcome (e.g. increased or decreased acute care use).  
41 161

42 162 The two researchers then jointly mapped recurrent patterns into explanatory context-mechanism-  
43 163 outcome (CMO) diagrams to illustrate how the different factors interact. Literature was also  
44 164 examined for opposing or conflicting viewpoints. These CMO diagrams were discussed with a third  
45 165 member of the research team (LC) to confirm consistent and logical development. Key findings were  
46 166 synthesised into overarching themes, which are referred to as 'theories' in the realist review  
47 167 approach.<sup>17</sup> Finally, a list of recommendations were developed from the findings and ordered by  
48 168 context to guide future RPM intervention design and implementation.  
49 169

### 50 170 **Patient and public involvement**

51 171 Patients or the public were not involved in the design, or conduct, or reporting, or dissemination  
52 172 plans of our research.  
53 173

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## 174 Results

175 Ninety-one articles from our previous review were evaluated to determine why RPM increased,  
176 decreased, or had no affect on acute care use. Thirty-one factors were identified and mapped onto  
177 two outcomes: 1) increased hospital use (21 factors) and 2) reduced hospital use (10 factors)  
178 (Figures 1 & 2). Factors were also ordered by the frequency of articles that reported them as  
179 possible influences on outcomes (represented by the size of each factor in Figure 1 and 2).

### 181 [Insert Figure 1]

182 **Figure 1** Factors associated with RPM intervention studies that reduced acute care use.

183 *The size of each box relates to the number of studies that identified each factor as having an important*  
184 *influence on the outcome.*

185 *CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring*

### 187 [Insert Figure 2]

188 **Figure 2** Factors associated with RPM interventions studies that increased acute care use.

189 *The size of each box relates to the number of studies that identified each factor as having an important*  
190 *influence on the outcome.*

191 *RPM: remote patient monitoring; Pt: patient*

## 193 Theories about how RPM works

194 It was identified that successful RPM interventions, in this case those interventions that successfully  
195 reduced acute care use, were those that: 1) *target populations at high risk*; 2) *accurately detect a*  
196 *decline in health*; 3) *were responsive and provided timely care*; 4) *provided personalised care*; 5)  
197 *enhanced self-management* and, 6) *ensured collaborative and coordinated care*. Each of these  
198 theories of intervention success are described below.

### 200 Target populations at high risk

201 Appropriate selection of patients for RPM is crucial if a change in acute care use is to be achieved.  
202 RPM interventions are likely to have more pronounced effects on acute care use when they are  
203 targeted towards populations with a high risk of hospitalisation (e.g. moderate-severe disease  
204 severity, multiple comorbidities).<sup>19</sup> Further, it is important for the intervention to be timed with  
205 periods of high-risk readmissions (e.g. the first 90 days post an index event). Delaying the delivering  
206 of RPM devices to patients may reduce the effect<sup>20</sup> (See Figure 3).

207 Patients who are more likely to present to hospital multiple times have a greater chance of reducing  
208 admissions due to more timely interventions. In practice, however, clinicians may have reservations  
209 about remotely assessing their most vulnerable and unwell patients. As described by Geller et al.,<sup>21</sup>  
210 *“in clinical practice telemedicine seems to be used mainly in patients with better prognosis, probably*  
211 *due to the belief that those who live longer may receive more (i.e. prolonged) benefit from*

1  
2  
3 212 *telemonitoring than sicker patients who should be seen in the office more frequently” (pg. 1124).*  
4 213 Consequently, clinicians may require additional information on how RPM can be safely delivered in  
5 214 high-risk cohorts.  
6  
7

8 215

9  
10 216 **[Insert Figure 3]**

11 217 *Figure 3. Proposed context-mechanism-outcome: target population*

12  
13 218

14  
15 219 ***Accurately detect a decline in health***

16  
17 220 RPM needs to accurately predict disease exacerbations by detecting a change in symptoms that  
18 221 relate to health deteriorations. This has been a challenge in certain populations such as COPD and  
19 222 heart failure patients which may have unpredictable disease progression. In the COPD population,  
20 223 multiple studies reported trying to determine the measurement (e.g. spirometry, oximetry, or a  
21 224 combination) which would mark the onset of an exacerbation,<sup>22-25</sup> however, none came to a  
22 225 definitive conclusion.<sup>26</sup> RPM can be used in these population groups to longitudinally track the  
23 226 progression of disease and develop parameters to be tested as predictors for future interventions.<sup>27</sup>

24  
25  
26  
27 227 In the heart failure population, physiological signs may not provide adequate warning of  
28 228 decompensation. Readmission in this cohort can be a complex interplay of multiple factors and is  
29 229 often not solely limited to physiological variables.<sup>28</sup> If deterioration occurs too quickly, there is  
30 230 limited opportunity to intervene.<sup>29</sup> Therefore, more investigation is required to try and accurately  
31 231 predict health declines for individual patients and accurately pin-point the best way for RPM to be  
32 232 used to support this patient population.  
33  
34

35 233 Implantable devices (e.g. pacemakers) have an additional advantage; continuous monitoring enables  
36 234 undiagnosed co-morbid conditions such as atrial fibrillation to be detected enabling pre-emptive  
37 235 intervention.<sup>30</sup> It can also improve the efficiency of outpatient clinical care by detecting device or  
38 236 lead malfunctions earlier.<sup>31</sup>  
39  
40

41 237

42  
43 238 ***Provide timely care via a responsive system***

44  
45 239 Any benefit from RPM is dependent on patients 1) using the system (e.g. timely data entry) and, 2)  
46 240 providers taking appropriate and equally timely action when out-of-range readings occur.<sup>30</sup>  
47 241 Therefore, RPM systems that use automated data entry wherever possible are preferable as they  
48 242 can reduce errors and delays due to manual entry. As technology improves, smartphone-based  
49 243 programs are likely to replace standard RPM equipment which may result in more consistent,  
50 244 accurate and timely data from patients.<sup>19</sup> For innovations that rely on manual data entry, RPM  
51 245 innovations need to be easy to use (e.g. enable efficient data entry, transportable) and useful for  
52 246 patients to ensure long term use and engagement.<sup>32</sup> Additionally, regular monitoring is required. For  
53 247 example, Srivastava et al.<sup>19</sup> routinely monitored data for abnormalities or lack of responses; if a  
54 248 patient did not submit data for three days, a call was initiated by nursing staff.  
55  
56  
57

58 249 On the staff end, RPM alerts need to be actioned with timely and appropriate responses; the speed  
59 250 of decision-making and frequency of monitoring is paramount.<sup>33</sup> A fast response often requires  
60 251 frequent contact with patients and effective bi-directional communication pathways between staff

1  
2  
3 252 and patients. For example, Trucco et al.<sup>34</sup> facilitated communication between families and the on-  
4 253 call team via a dedicated phone number or email address. Multiple studies report the importance of  
5 254 dedicated care (e.g. providing an RPM nurse or dedicated case manager) in improving response  
6 255 time.<sup>33, 35-38</sup> This is supported by the literature with findings that patients who received either basic  
7 256 or intensive case management spend less time in hospital than those without.<sup>39</sup> “Fast tracked”  
8 257 access to primary care providers was used in the intervention reported by Pedone et al.<sup>40</sup> when  
9 258 abnormalities were presented, or new symptoms arose. They reported that a new model of care,  
10 259 rather than simply implementing a new technology, was required to obtain sizable benefits in terms  
11 260 of hospitalisation outcomes.<sup>40</sup> Where possible, RPM should be embedded into the system and  
12 261 provide seamless interaction between patients and the healthcare system with minimal  
13 262 encumbrance on both ends.<sup>19</sup> The proposed context-mechanism-outcome diagram is provided in  
14 263 Figure 4.

15 264  
16 265 **[Insert Figure 4]**

17 266 *Figure 4. Proposed context-mechanism-outcome: timely care*

### 18 267 19 268 **Provide personalised care**

20 269 Providing a patient-centric and personalised approach was also an important factor in determining  
21 270 the success of an RPM intervention in reducing acute care use.<sup>19</sup> Firstly, the development of the RPM  
22 271 innovation needs to be co-designed with patients and their families to ensure it meets their needs  
23 272 and maximises acceptance and uptake.<sup>41</sup> Training patients on how to use the device will likely also  
24 273 need to be personalised and at times repeated. RPM alerts can also be personalised by using  
25 274 individual data to determine alert thresholds. Koelher et al.<sup>42</sup> recommended defining a risk category  
26 275 for each individual patient based on their positive results (derived from biometric data). One study  
27 276 author requested personalised parameters and treatment guidelines from each patient’s treating  
28 277 physician.<sup>43</sup> Determining appropriate parameters for RPM applications (personalised or not) enables  
29 278 the treating team to be alerted to any biometric measurements that fall outside of the parameter  
30 279 ranges. To enable personalised parameters to be developed, physicians need to be engaged in the  
31 280 RPM process for their patient early. The response by the RPM monitoring team also needs to be  
32 281 tailored; considering the person’s medical, social and emotional needs.

### 33 282 34 283 **Enhance self-management**

35 284 To successfully reduce acute care use, RPM interventions should include support and education to  
36 285 increase self-management skills. Through developing knowledge, skills and positive behaviours (e.g.  
37 286 medication adherence), patients are more likely to be able to effectively manage their condition  
38 287 with the aid of RPM (see Figure 5).<sup>44</sup> Additionally, increased awareness of signs and symptoms of  
39 288 disease progression that often occurs when patients use RPM can prompt them to contact their  
40 289 healthcare provider for timely management.<sup>44</sup> Providing feedback from RPM data in a way that  
41 290 empowers patients to take control of their own health is important. Koelher et al.<sup>42</sup> reported that  
42 291 this needs to be a comprehensive approach including education and patient involvement when  
43 292 developing management strategies. In some instances, RPM interventions were discontinued once  
44 293 patients were able to correctly correlate their personal symptoms and seek help when required.<sup>43</sup>



1  
2  
3 294 Conversely, some RPM interventions that were unsuccessful in reducing hospitalisation events  
4 295 reported patients becoming overly reliant on the RPM team, for instance, alerting the team when an  
5 296 issue arose rather than developing autonomous self-management skills for their condition.  
7 297 Additionally, some known important factors such as medication adherence were not always  
8 298 measured and present a lost opportunity in many RPM innovations. Medication adherence and  
9 299 timely changes to medications are reported to confer substantial benefits for patients.<sup>42</sup>

11 300 **[Insert Figure 5]**

12 301  
13  
14 302 *Figure 5. Proposed context-mechanism-outcome: self-management*

### 15 303 16 17 304 **Ensure collaborative and coordinated care**

18  
19 305 Successful RPM studies demonstrated increased connection and communication between  
20 306 healthcare staff and patients.<sup>31</sup> Multidisciplinary team-based interventions that combine feedback  
21 307 (automated and/or provider-initiated) with other approaches (e.g. coaching, motivational  
22 308 interviews, and shared decision-making) are more likely to result in improvement in adherence.<sup>45</sup>  
23 309 Involvement of primary care is crucial. As high-risk patients are often managed by primary and  
24 310 specialty care, both hospital and primary care settings should be involved in RPM interventions.<sup>46</sup>  
25 311 Involvement of key stakeholders is required to improve continuity of care.<sup>47</sup> Beyond healthcare  
26 312 professionals, the RPM intervention should also aim to include families and carers as key  
27 313 stakeholders in the long-term management of the person's condition. To increase primary carers'  
28 314 acceptance of and adherence to RPM, they must be involved very early on. To institute an initial  
29 315 change of role, staff incentives (e.g. financial payments) may be required.<sup>27</sup> Additionally, nursing  
30 316 staff should be considered as having leading roles in RPM interventions.<sup>48</sup> Further, institutional  
31 317 support is required for these initiatives and reorganisation of care processes should be carefully  
32 318 planned and implemented.<sup>48</sup>

### 33 319 **Factors that resulted in increased acute care use**

34 320 A range of factors were identified as having a negative influence on hospital use (increasing  
35 321 admissions) (Figure 2). Many of the identified factors are the reverse of what has been described  
36 322 above. For example, not targeting populations at high risk, not integrating RPM into the workflow, or  
37 323 using systems that have measurement errors. For example, multiple study authors reported slow  
38 324 alert response times (N=6)<sup>32, 49-53</sup> and low patient or clinician adherence (N=11)<sup>19, 20, 28, 32, 45, 54-59</sup> as  
39 325 important factors resulting in no change or an increase in acute care use in the RPM group. There  
40 326 also appears to be a delicate balance between providing a supportive environment that empowers  
41 327 patients to self-manage versus having patients become reliant on the RPM device and/or the  
42 328 monitoring team.

### 43 329 44 330 **Recommendations for RPM**

45 331 We synthesised multiple recommendations to assist in the design and implementation of RPM  
46 332 interventions (Figure 6).  
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333 When designing RPM devices, it is crucial that the measured biometrics accurately predict disease  
334 exacerbations. Alert thresholds need to be carefully determined to ensure they are sensitive to  
335 physiological changes without being too high, and where possible tailored to the patient and disease  
336 state. Further, the transmission of data needs to be reliable, and if possible, automatic.

337 It is essential that RPM devices are co-designed with consumers and providers to improve usability  
338 and engagement with the RPM system. It is likely that making the device interactive and building in  
339 feedback loops between the patient and clinician will enhance engagement. However, if this  
340 increases the provider's workload it may discourage provider engagement. Multidisciplinary team  
341 interventions that combine feedback with other approaches like patient education, motivational  
342 interviewing, coaching or shared decision-making are likely to be more effective long-term.<sup>60</sup>

343 At the organisation level, having dedicated professionals responsible for monitoring data and  
344 communicating with patients and the healthcare team can improve the timeliness and coordination  
345 of care. Studies with nursing staff in these leading and case-management roles appeared to be more  
346 effective.<sup>48</sup> RPM also needs to be embedded into the health system to provide seamless interaction  
347 between patients and the healthcare system. This may require reorganisation of care and additional  
348 resources (physical and personnel) to support the intervention.

349

350 **[Insert Figure 6]**

351 *Figure 6. Recommendations to enhance RPM and reduce acute care use*

352

## 353 Discussion

354 We found that RPM interventions were successful at reducing acute care use when they  
355 incorporated a number of elements including: accurately predicting a decline in health or disease  
356 exacerbation, timely response to alerts, personalised patient parameters, and a focus on enhancing  
357 patient self-management. Additionally, collaboration between specialists and primary care provides  
358 was required to improve the continuity of care To the best of our knowledge, this is the first review  
359 to elucidate why some RPM interventions are more successful than others in reducing acute care  
360 use.

361 RPM interventions are complex because they typically involving multiple components (e.g. data  
362 collection, education, feedback) and various stakeholders across different settings (e.g. community,  
363 primary and tertiary care). Given the complexity of RPM interventions, it is perhaps unsurprising that  
364 RPM studies have resulted in so much variation in the effects demonstrated regarding changes in  
365 acute care use. To date, much of the focus of RPM innovations has been on the design and  
366 development of the technology.<sup>61, 62</sup> While functioning technology that accurate detects a decline in  
367 health is important, to deliver significant benefits RPM alerts must also lead to an actionable and  
368 timely responses. To achieve positive results at the healthcare system level, RPM interventions  
369 require a change to the *model of care* rather than simple technology implementation.<sup>63</sup>

370 To be successful, the right patients need to be recruited at the right time. Patients with greater  
371 disease severity and at high risk of readmissions appear to confer the greatest benefit of RPM  
372 interventions in terms of reduced acute care use.<sup>64</sup> For instance, a recent consensus statement from  
373 the Heart Failure Society of America<sup>65</sup> broadly concluded that heart failure RPM had the most impact

374 when patients were most at risk (e.g., recent hospitalisation, prone to fluid overload, and struggles  
375 with medication adherence). Additionally, RPM should target patients who are willing and likely to  
376 adhere with RPM regimes.

377 While our study focuses on acute hospital use, other authors have investigated patient-related  
378 factors that may support long-term monitoring of conditions. For example, Huygens suggests there  
379 is a relationship between perceived disease controllability and patients' willingness to self-monitor.<sup>66</sup>  
380 Patients with diabetes, asthma and hypertension were most willing to self-monitor. In contrast,  
381 patients with rheumatism, migraines and other neurological disorders were less willing. The  
382 intervention design can facilitate engagement and use. Hong and Lee<sup>64</sup> determined that  
383 interventions with an educational component such as self-management programs have greater  
384 effects. Another consideration is the patient's social circumstance. One study found that RPM  
385 significantly improved outcomes for socially isolated patients,<sup>67</sup> potentially due to the delay in care  
386 access that these patients may face. Conversely, for socially connected patients, outcomes appear to  
387 be enhanced by training caregivers.<sup>29, 68</sup>

388 Interventions based on health behaviour models and personalised coaching were most successful.<sup>69</sup>  
389 The findings of this review parallel some of the themes in a review of patient experiences of RPM by  
390 Walker et al.<sup>70</sup> Similarly, self-management and early identification of clinical exacerbations were key  
391 to preventing hospitalisation. From the patient perspective, self-management was achieved by  
392 increasing confidence and providing a sense of safety. Shared decision making was identified as a  
393 key mechanism to preventing hospitalisation. Conversely, interventions that provided information  
394 but did not equip patients to self-manage were potentially at greater risk of having patients become  
395 overly reliant on the RPM team.

396 Patients have previously reported concerns about being lost in the data or losing interpersonal  
397 connections with health professionals and a reluctance to try something new, especially if unfamiliar  
398 with technology.<sup>70</sup> Our findings substantiate the importance of co-designing RPM interventions with  
399 consumers to ensure they are easy to use and provide useful feedback to maintain adherence and  
400 engagement. Building rapport, providing training (sometimes multiple times) and having a two-way  
401 interactive relationship between the patient and the RPM team is crucial. Alternatively, a lack of  
402 education and timely response were identified as factors that increased acute care use.

403 Included studies within our review had multiple study design issues. Typically, with many of these  
404 studies it is not possible (or ethical) to blind participants. Therefore, selection bias may have affected  
405 results if health professionals pragmatically selected more willing or engaged patients to participate  
406 in the trials. However, in real-world clinical settings it is likely (and appropriate) that participants are  
407 provided with options regarding their follow-up care. The observer or Hawthorne effect<sup>71</sup> may be at  
408 play with participants potentially acting differently due to a belief that they are being watched. Such  
409 an effect may reduce with time, and some trial lengths may have been too short for this effect to  
410 wear off. Potentially the higher number of studies reporting positive outcomes may be due to a  
411 reporting bias within the literature; consequently, there were a higher number of factors discussed  
412 in relation to reducing (n=21) rather than increasing acute care use (n=10).

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414 Our review was strengthened by a comprehensive search and inclusivity of diverse RPM  
415 interventions across a broad spectrum of conditions and contexts. The novel use of realist review  
416 methodology and development of theory-based constructs helped to systematically identify factors  
417 impacting upon implementation. However, while our focus was on acute care use, other aspects of  
418 care may have been overlooked that relate to care quality. Further, it is possible that reducing  
419 hospital admissions may shift care and associated costs to the primary care setting and potentially  
420 result in additional pressure and stress on different aspects of the system. Additionally, the theories

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3 421 that have been developed are based on both our and the primary study authors' interpretation of  
4 422 findings in many instances and not experimental evidence.  
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## 8 424 **Conclusion**

10 425 RPM interventions have the potential to reduce acute care use when they are targeted to  
11 426 appropriate populations and disease states, designed well, and implemented with patients and  
12 427 providers in mind. This review has highlighted important considerations for developing effective  
13 428 RPM devices, systems, and telehealth models of care. To achieve significant changes in acute care  
14 429 use, RPM data needs to be routinely entered and checked, automated where possible, alerts need to  
15 430 accurately highlight when a person's data is beyond an acceptable range (for that person), and  
16 431 healthcare staff need to respond in a timely and appropriate manner. Further, information and  
17 432 feedback needs be provided to patients in a way that empowers them to self-manage their  
18 433 condition. If designed with these considerations in mind, RPM interventions are more likely to be  
19 434 effective at reducing acute care use. Future studies should investigate any unintended consequences  
20 435 of RPM and cost implications resulting from the shifting of care.  
21 436

## 25 437 **List of abbreviations**

27 438 COPD: chronic obstructive pulmonary disease; CMO: context-mechanism-outcome; PROSPERO:  
28 439 Prospective Register of Systematic Reviews; RAMESES: Realist and Meta-narrative Evidence  
29 440 Synthesis: Evolving Standards; RPM: Remote patient monitoring.

## 32 441 **Declarations**

34 442 Ethics approval and consent to participate: Not applicable

35 443

36 444 Consent for publication: All authors consent to publication

37 445

38 446 Availability of data and materials: Not applicable

39 447

40 448 Competing interests: None to declare

41 449

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45 453

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47 455 study design. Searches and data extraction were carried out by ET and MT with support from LC.

48 456 Data analysis was performed by ET, MT and LC. Manuscript was drafted by ET, MT, AB and LC.

49 457 Critical review of manuscript was undertaken by HH, CS, AS, VGR. All authors approved the final  
50 458 manuscript.

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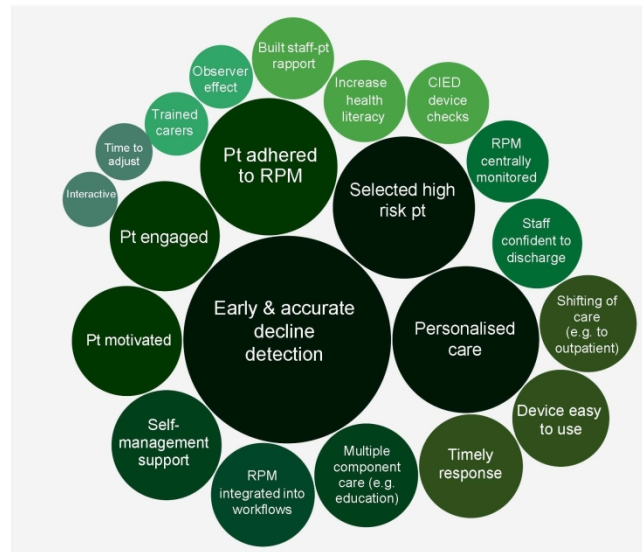


Figure 1 Factors associated with RPM intervention studies that reduced acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

CIED: Cardiac implantable electronic devices; Pt: patient; RPM: remote patient monitoring

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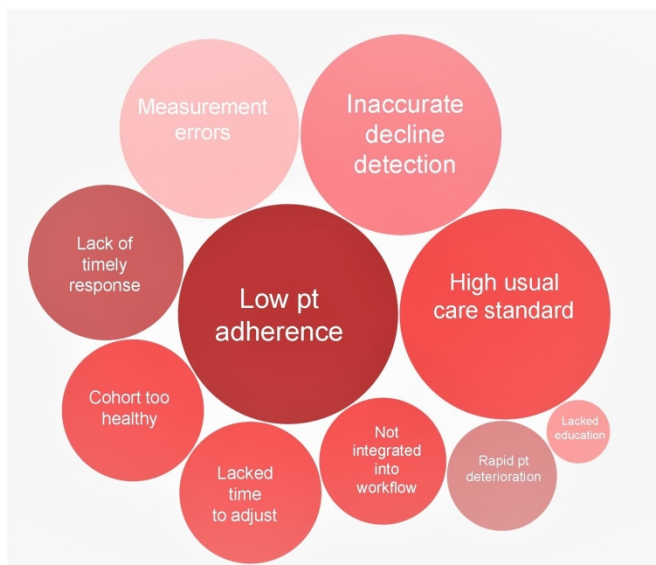


Figure 2 Factors associated with RPM interventions studies that increased acute care use. The size of each box relates to the number of studies that identified each factor as having an important influence on the outcome.

RPM: remote patient monitoring; Pt: patient

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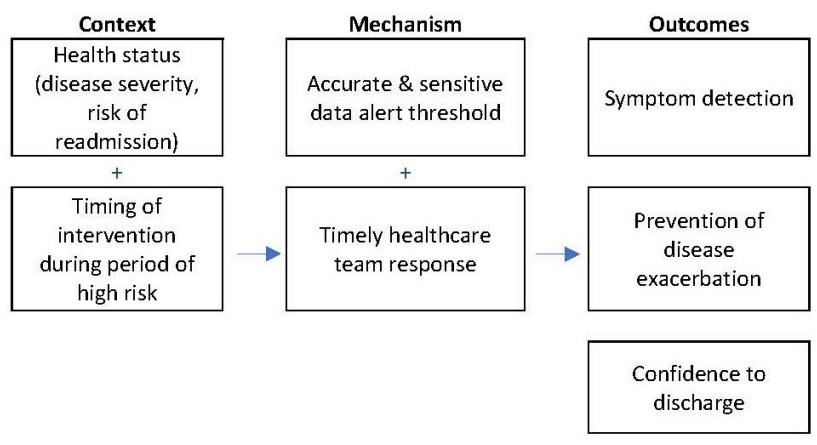


Figure 3. Proposed context-mechanism-outcome: target population

310x171mm (96 x 96 DPI)

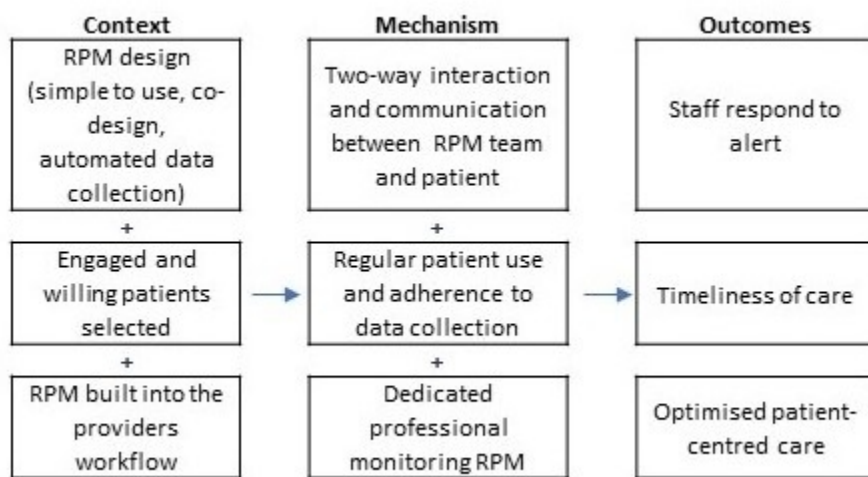


Figure 4. Proposed context-mechanism-outcome: timely care

121x72mm (96 x 96 DPI)

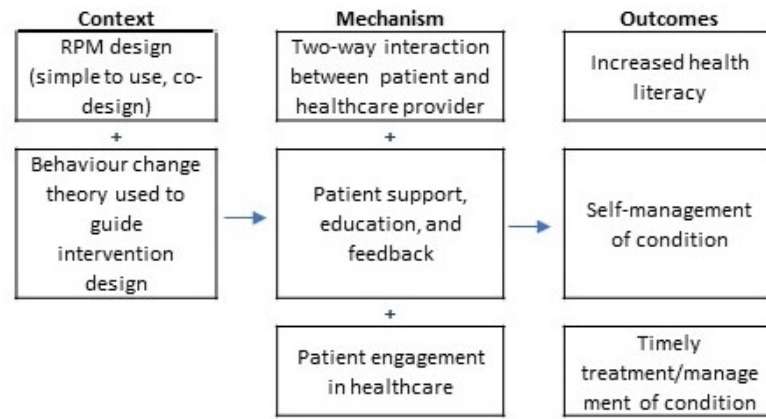


Figure 5. Proposed context-mechanism-outcome: self-management

150x87mm (96 x 96 DPI)

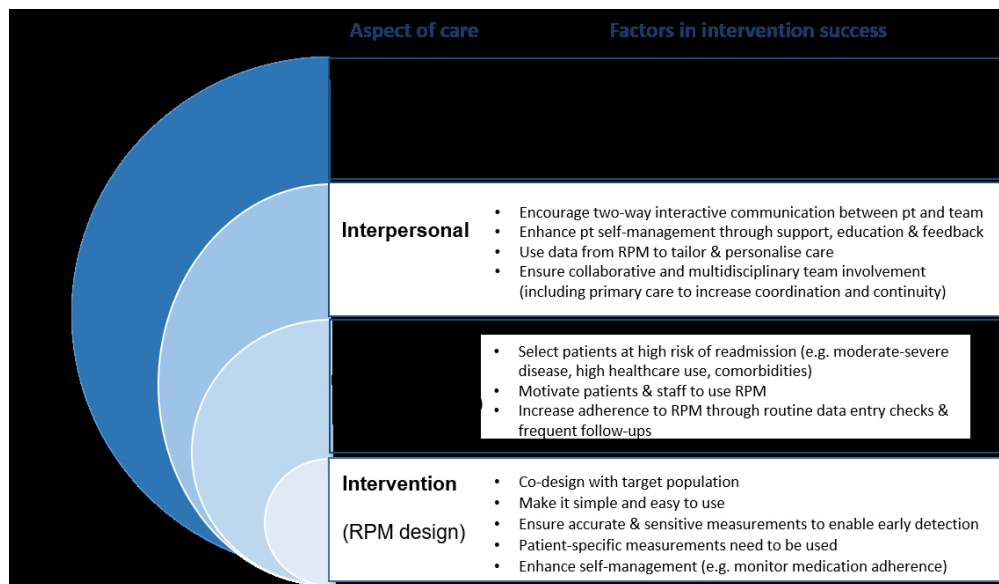
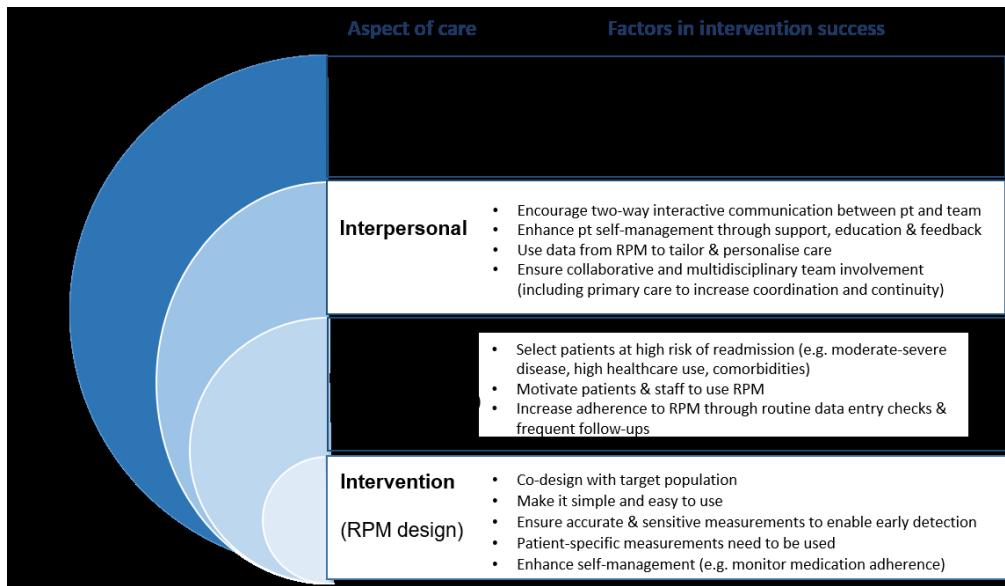


Figure 6: Recommendations to enhance RPM and reduce acute care use

489x284mm (59 x 59 DPI)

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489x284mm (59 x 59 DPI)

## Appendix A

### RAMESES publication standards: realist synthesis

Wong, G., Greenhalgh, T., Westhorp, G. *et al.* RAMESES publication standards: realist syntheses. *BMC Med* **11**, 21 (2013).

<https://doi.org/10.1186/1741-7015-11-21>

TITLE			Pg No.
1		In the title, identify the document as a realist synthesis or review	1
ABSTRACT			
2		While acknowledging publication requirements and house style, abstracts should ideally contain brief details of: the study's background, review question or objectives; search strategy; methods of selection, appraisal, analysis and synthesis of sources; main results; and implications for practice.	2
INTRODUCTION			
3	Rationale for review	Explain why the review is needed and what it is likely to contribute to existing understanding of the topic area.	3
4	Objectives and focus of review	State the objective(s) of the review and/or the review question(s). Define and provide a rationale for the focus of the review.	3
METHODS			
5	Changes in the review process	Any changes made to the review process that was initially planned should be briefly described and justified.	N/A



TITLE			Pg No.
6	Rationale for using realist synthesis	Explain why realist synthesis was considered the most appropriate method to use.	4
7	Scoping the literature	Describe and justify the initial process of exploratory scoping of the literature.	4
8	Searching processes	While considering specific requirements of the journal or other publication outlet, state and provide a rationale for how the iterative searching was done. Provide details on all the sources accessed for information in the review. Where searching in electronic databases has taken place, the details should include, for example, name of database, search terms, dates of coverage and date last searched. If individuals familiar with the relevant literature and/or topic area were contacted, indicate how they were identified and selected.	4
9	Selection and appraisal of documents	Explain how judgements were made about including and excluding data from documents, and justify these.	4. also additional details provided in previously published paper
10	Data extraction	Describe and explain which data or information were extracted from the included documents and justify this selection.	As above
11	Analysis and synthesis processes	Describe the analysis and synthesis processes in detail. This section should include information on the constructs analyzed and describe the analytic process.	As above
RESULTS			
12	Document flow diagram	Provide details on the number of documents assessed for eligibility and included in the review with reasons for exclusion at each stage as well as an indication of their source of origin (for example, from searching databases, reference lists and so on). You may consider	This paper included articles from a previously published review that followed the PRISMA guidelines – the flow

TITLE			Pg No.
		using the example templates (which are likely to need modification to suit the data) that are provided.	diagram is published within that paper.
13	Document characteristics	Provide information on the characteristics of the documents included in the review.	4-8
14	Main findings	Present the key findings with a specific focus on theory building and testing.	4-8
DISCUSSION			
15	Summary of findings	Summarize the main findings, taking into account the review's objective(s), research question(s), focus and intended audience(s).	9
16	Strengths, limitations and future research directions	Discuss both the strengths of the review and its limitations. These should include (but need not be restricted to) (a) consideration of all the steps in the review process and (b) comment on the overall strength of evidence supporting the explanatory insights which emerged. The limitations identified may point to areas where further work is needed.	10
17	Comparison with existing literature	Where applicable, compare and contrast the review's findings with the existing literature (for example, other reviews) on the same topic.	9-10
18	Conclusion and recommendations	List the main implications of the findings and place these in the context of other relevant literature. If appropriate, offer recommendations for policy and practice.	10/11
19	Funding	Provide details of funding source (if any) for the review, the role played by the funder (if any) and any conflicts of interests of the reviewers.	1