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Interactive remote patient monitoring devices for managing chronic health conditions: systematic review and meta-analysis

Authors

Donato G. Leo,[1,2] Benjamin J. R. Buckley,[1,2] Mahin Chowdhury,[1] Stephanie L. Harrison,[1,2] Masoud Isanejad,[2,3] Gregory Y. H. Lip, [1,2] David J. Wright,[2] Deirdre A. Lane; [1,2] on behalf of the TAILOR investigators

Affiliations

[1]Department of Cardiovascular and Metabolic Medicine, Institute of Life Course and Medical Sciences, Faculty of Health and Life Sciences, University of Liverpool, Liverpool, UK;

[2]Liverpool Centre for Cardiovascular Science, University of Liverpool and Liverpool Heart & Chest Hospital, Liverpool, United Kingdom;

[3]Department of Musculoskeletal Ageing, Institute of Life Course and Medical Sciences, Faculty of Health and Life Sciences, University of Liverpool, Liverpool, United Kingdom;

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Corresponding author

Professor Deirdre Lane, Liverpool Centre for Cardiovascular Sciences and Department of Cardiovascular and Metabolic Medicine, Institute of Life Course and Medical Sciences, Faculty of Health and Life Sciences, University of Liverpool, Liverpool, UK;

deirdre.lane@liverpool.ac.uk

ABSTRACT

Background: Telemedicine is an expanding and feasible approach to improve medical care for patients with long-term conditions. However, there is a poor understanding of patients' acceptability of this intervention and their rate of uptake.

Objective: To systematically review the current evidence on telemonitoring in the management of patients with long-term conditions, and to evaluate the patients' uptake and acceptability of this technology.

Methods: MEDLINE, SCOPUS, and CENTRAL were searched from date of inception to 5 February 2021, with no language restrictions. Studies were eligible for inclusion if they reported any of the following outcomes: (i) intervention uptake and adherence; (ii) study retention; (iii) patient acceptability, satisfaction and experience using intervention: (iv) changes in physiological values; (v) all-cause and cardiovascular related hospitalization; (vi) all-cause and disease specific mortality; (vii) patient-reported outcome measures; (viii) quality of life. Two reviewers independently assessed articles for eligibility.

Results: Ninety-six studies were included and fifty-eight were pooled for meta-analyses. Meta-analyses showed reduction in mortality (RR= 0.71, 95% CI 0.56 to 0.89, P=0.003, I^2=0%); and improvements in BP (MD -3.85 mmHg, 95% CI -7.03 to -0.68, P<.02, I^2= 100%) and HbA1c (MD -0.33, 95% CI -0.57 to -0.09, *P=.008*, I^2= 99%); but no significant improvements in quality of life (MD 1.45, 95% CI -0.10 to 3, *P=.07*, I^2=80%); and increased risk of hospitalization (RR 1.02, 95% CI 0.85 to 1.23, *P=.81*, I^2=79%) with telemonitoring compared to usual care. Twelve studies reported adherence outcomes and nine on satisfaction/acceptance, however heterogeneity in the assessment methods meant meta-analysis could not be performed.

Conclusion: Telemonitoring is a valid alternative to usual care, reducing mortality and improving self-management of the disease, with patients reporting good satisfaction and adherence. Further studies are required to address some potential concerns regarding higher hospitalisation rates and a lack of a positive impact on patients' quality of life.

This systematic review was registered on PROSPERO (CRD42021236291).

Key Words: chronic condition; telemonitoring; telemedicine; e-health, self-monitoring, systematic review, meta-analysis

INTRODUCTION

In the UK, 15 million people live with at least one long-term condition[1], with their care accounting for 70% of the national health service budget [1]. Those with long-term conditions have significantly reduced quality of life, as well as increased risk of morbidity and mortality[2, 3]. Cardiovascular disease, diabetes mellitus and chronic obstructive pulmonary disease (COPD) are the most common chronic conditions worldwide [4]. Lack of care coordination [5, 6] and care planning consultation [5, 6] are among the common barriers patients with long-term conditions face. Additionally, the restrictions induced by the COVID-19 pandemic have amplified the challenges that people living with chronic disease experience in terms of managing their health and accessing healthcare [7].

Advances in technology have the potential to support patients with long-term conditions to manage their health at home, making the provision of remote healthcare more accessible and efficient [8]. Virtual health care and telemedicine include the remote delivery of care using communication technology (e.g. videoconference software; online applications; home-based health measurement) to enable consultations between patients and their care team, providing continuous monitoring of relevant health parameters. This allows healthcare professionals to promptly respond to changes in patient health status and adapt their clinical management in real-time [9].

Recent evidence has deemed telemedicine feasible for patients with long-term conditions and effective in terms of improving medical care [10]. As telemedicine is a rapidly expanding and changing field, recent umbrella reviews [10, 11] that take into account older primary studies have potentially made conclusions based on non-contemporary data. Therefore, the aim of this systematic review is to update and expand the current literature on telemonitoring by better defining the interventions included to encompass the role that

interactive, two-way communication devices, have in improving the care of patients with long-term conditions, as well as to evaluate patient uptake and acceptability of this technology.

METHODS

This systematic review was registered on the International Prospective Register of Systematic Reviews – PROSPERO (CRD42021236291) and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [12].

This review aimed to address the following research questions:

i. What is the rate of uptake, patient retention and patient satisfaction when using interactive remote patient monitoring devices to manage chronic health conditions?
ii. What factors are associated with patient retention and satisfaction when using interactive remote patient monitoring devices to manage chronic health conditions?
iii. Does the use of interactive remote patient monitoring devices for the management of chronic health conditions impact patient outcomes (e.g. changes in physiological measurements, quality of life, all-cause and cardiovascular-related hospitalisations, all-cause and disease-specific mortality)?

Criteria for considering studies to include in the review

Studies carried out in any setting aiming to evaluate telemonitoring interventions for participants with at least one chronic condition among the following: cardiovascular disease, chronic obstructive pulmonary disease, and/or diabetes mellitus, were eligible for inclusion. All randomised controlled trials and non-randomised trials, before-and-after (pre-post) studies and interrupted time series were considered for inclusion. Cross-sectional studies

and case-reports were excluded. Qualitative studies were included to assess participant satisfaction. Ongoing studies (if any) were also considered and presented in a dedicated table.

Participants

Adults (aged 18 years or older) were eligible for inclusion in this review if they reported one or more of the following chronic health conditions: cardiovascular diseases (e.g., coronary artery disease, atrial fibrillation, stroke, heart failure, hypertension), chronic obstructive pulmonary disease (COPD), or diabetes mellitus.

Intervention

Interventions designed to remotely collect health information from patients using digital technologies and electronically transfer the information to healthcare professionals for monitoring and assessment were eligible for inclusion. Only interventions where the participant received a digital device for remote patient monitoring, and the participant or their caregiver took physiological measurements and either inputted the information into the device or the device automatically uploaded the data were included. Health devices suitable for inclusion had to transmit data to the participant's healthcare team, and the participant's healthcare team had to monitor the information received, assessing the information and making appropriate changes to the participant's treatment accordingly. Two-way exchange of information was required for the study to be included.

Comparator

Studies where usual care or a different intervention was used as control or comparator were also considered as eligible for inclusion, as were studies that did not have a control group.

Outcomes

The primary outcomes of interest were: (i) intervention uptake (number of people willing to participate in the intervention) and adherence (level of commitment of the patient to the prescribed intervention); (ii) study retention (number of people that completed the intervention); and (iii) patient acceptability (level of acceptance of the intervention by the participants), satisfaction (number of participants pleased with the intervention) and experience using the intervention. Secondary outcomes included: (i) changes in physiological measurements (oxygen saturation, blood pressure, blood glucose level, etc.); (ii) all-cause and cardiovascular-related hospitalisations; (iii) all-cause and disease-specific mortality; (iv) patient-reported outcome measures (e.g., mental well-being, depression, and anxiety questionnaires); (v) quality of life, quality adjusted life years and any other health economic outcomes reported by the studies. All studies that reported one or more of these outcomes were considered eligible for inclusion.

Search Strategy

The search strategy was developed by the review team who agreed the key terms. Medical subject headings (MeSH) terms and synonyms for the different terms such as “telemedicine, digital monitoring, e-health”, etc. (see Supplementary Table 1) were used and combined with Boolean operators, proximity operators, truncations, and wildcards. MEDLINE, SCOPUS and the Cochrane Central Register of Controlled Trials (CENTRAL) were searched from the date of inception to 5 February 2021 for relevant studies. There were no language restrictions but availability of the full text was a requirement for inclusion. Search results were managed using EndNote X9.3.3.

Study Selection

Two reviewers (MC, DGL) independently screened the titles and abstracts of the studies retrieved by the databases against the search criteria. Additional screening of the preliminary results was independently undertaken by three other reviewers (BB, SH, MI). The full texts of all potentially relevant articles were retrieved and independently assessed by the reviewers in duplicate. Any disagreement was resolved through discussion with the senior author (DL).

Data Extraction

Data extraction was conducted independently by two reviewers (DGL, MC). The following information was extracted: (i) authors, year, country, reference; (ii) study aim; (iii) study characteristics (study design and sample size); (iv) participant characteristics (age, sex, ethnicity); (v) health condition; (vi) intervention (type of telemedicine device, input of the data – manual or automated, delivery of the intervention, staff involved, duration and frequency of the intervention, follow-up points); (vii) comparator(s) (usual care, different intervention, no intervention); and (viii) outcomes (primary and secondary as reported by the study).

Risk of Bias Assessment

Six authors (DGL, MC, BB, SH, MI, DL) independently assessed the individual studies for risk of bias in duplicate and any discrepancies were resolved via discussion or referral to a third reviewer, as required. For randomised controlled trials (RCTs), the Cochrane Risk of Bias v.2 (RoB2) tool [13] was used. For non-randomized studies, the Risk Of Bias In Non-randomised Studies of Interventions (ROBINS-I) [14] was used.

Data Synthesis

Meta-analyses were conducted for comparable studies. Primary and secondary outcome effect measures with 95% confidence intervals were pooled using RevMan software [15]. Results are presented visually using Forest plots. Where continuous data was not homogeneous, an estimate of the standardised mean difference with 95% confidence intervals was calculated. For studies where quantitative data were too few or too heterogeneous, a narrative synthesis approach was used.

Dichotomous analyses were conducted, using the number of events and total sample size as reported in the included studies. Results of the selected studies were combined using the Mantel-Haenszel method. Effect sizes were expressed as relative risk and 95% confidence intervals. Random-effect models were applied to all meta-analyses due to heterogeneity in study characteristics and populations. Heterogeneity was quantitatively assessed using Higgins's index (I^2).

For analysis of quality of life, the post-intervention scores, as reported by the included studies, were used. Where the standard deviation (SD) was not reported, it was calculated using the calculator function available in RevMan. For analysis of changes in physiological parameters (blood pressure and glycated haemoglobin, $HbA1_C$) and quality of life, results of the selected studies were combined using the generic inverse variance method. Effect sizes were expressed as mean difference and ±SD.

Findings from included qualitative studies will be synthesised elsewhere using a meta-aggregative approach to data synthesis.

RESULTS

The database searches identified 10,401 papers. After independent screening for titles and abstract by two study authors, 10,273 papers were determined to be duplicates or not

eligible. After screening against inclusion/exclusion criteria, of the remaining 128 papers, 96 (75%) were included. No ongoing studies were found (Figure 1). A full list of the excluded studies with reasons for exclusion is provided in the Supplementary Table 2. Full-texts for all 96 included [16-112] papers were retrieved.

No study reporting outcomes related to intervention uptake, study retention and patient acceptability were identified by our search, and therefore these outcomes could not be analysed. The following analyses and results concern only patients' adherence and satisfaction, as well as clinical and patients reported outcomes.

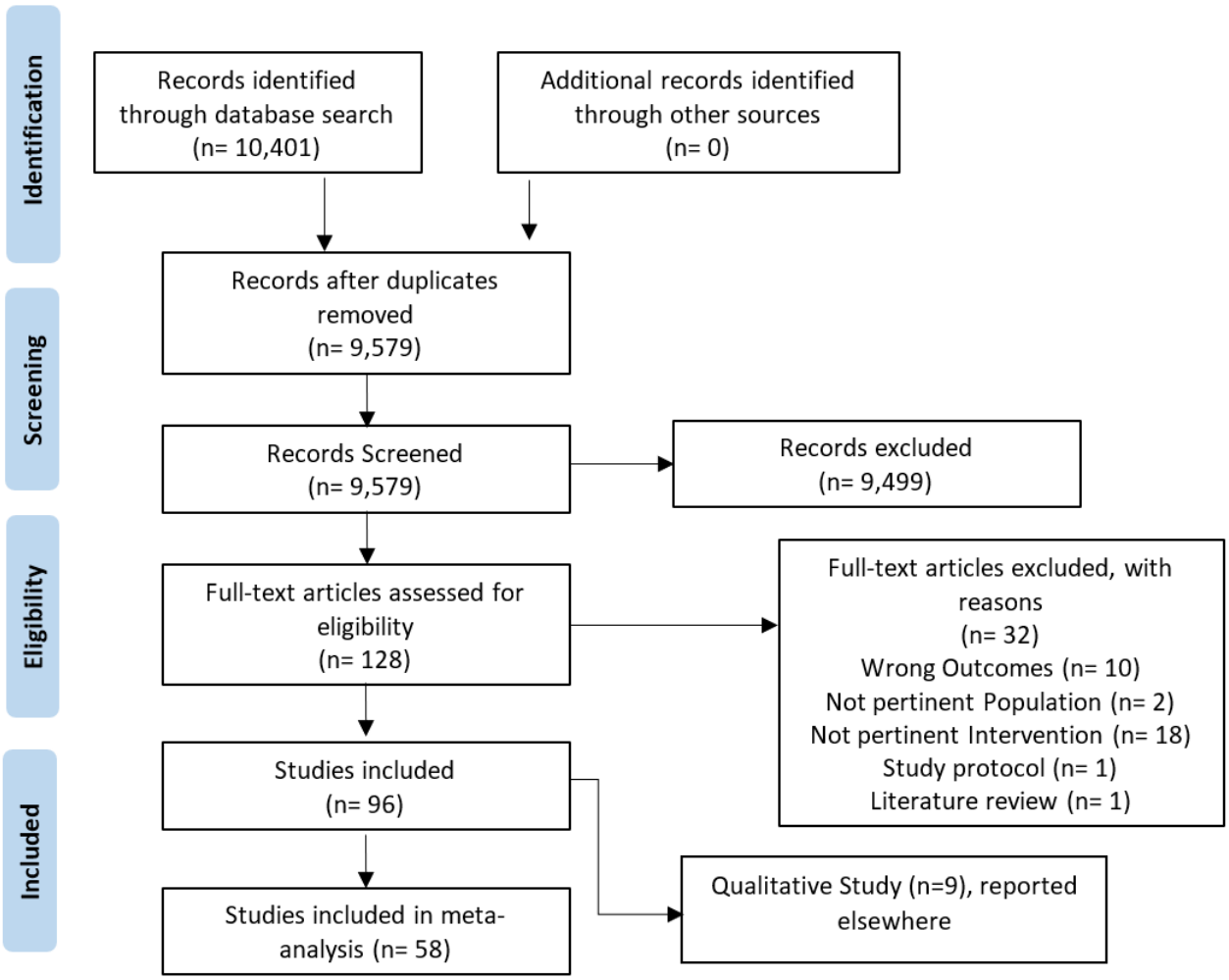

Figure 1. PRISMA diagram depicting screening and study selection process.

Characteristics of the included studies

The included studies were published between 1998 and 2020, with sample sizes ranging from 20 [39, 102] to 3,562 [105] participants, with a total sample of 26,167 participants. The mean ages ranged from 44[25] to 78[110] years, and the proportion of males varied from 25% [54] to 76% [94]. The majority of the included studies were conducted in the UK (n=21), and in the USA (n=29), with additional studies conducted in Belgium (n=2), Canada (n=4), Denmark (n=5), Poland (n=2), Singapore (n=2), South Korea (n=2), Spain (n=9), Germany (n=4), Italy (n=6) (Table 1). Additionally, the following countries had one study each: Australia [40], China [102], Finland [109], Greece [52], Hong Kong [31], Israel [17], Japan [69], Malaysia [70], Netherlands [28], and Taiwan [32] (Table 1).

Populations in the included studies comprised patients with diabetes (n=27 studies), cardiovascular disease (stroke, atrial fibrillation, hypertension, heart failure, n=52 studies), COPD patients (n=12 studies), and those with mixed chronic conditions (diabetes, hypertension, COPD, n=5 studies) (Table 1).

Types of intervention

The studies varied in their design, type of telemonitoring system used, and method of delivery (Table 1). Most (n=64) were RCTs, with four non-randomised control studies, two cluster randomised, 10 longitudinal studies, four retrospective analyses, three pre-post analyses, and nine with mixed-methods/qualitative design. Most studies (n=88) used telemonitoring systems that collected patients' information via computers, tablets or dedicated devices (e.g. modem) and transferred these data to an online server. Some studies collected patients' data via SMS (n=3) or by telephone (n=4). Four studies provided educational videos to increase patients' knowledge of the disease. Length of the intervention was highly variable, with five studies assessing over a short period of time (7 to

45 days), 20 over a 2 to 4 month period, and most interventions lasting 6 to 12 months. Follow-up periods were inconsistent among studies, and where present ranged from 3 to 18 months.

Types of comparators

Most studies (n=79, 82%) compared the intervention to usual care, which consisted of routine visits (outpatient clinics) and in-person consultations with General Practitioners (GPs) or the hospital care team (Table 1). Ten studies did not have a control group. One study (1%) asked the control group to manually record their data in a diary. Two studies (2%) used educational videos in the control group to improve patients' knowledge of the disease, another two studies (2%) compared the intervention to another telemonitoring device and one study (1%) compared the intervention (telemonitoring device) to telephone communication. One study (1%) used a similar intervention as control comparing patients with and without heart failure.

Types of outcomes

Twelve studies (13%) reported adherence to the intervention, including nine studies in those with cardiovascular disease, two in patients with diabetes, and one in COPD patients (Table 1). Patients' satisfaction with the intervention was assessed in nine studies (9%, n=2 with cardiovascular disease patients, n=3 with diabetic patients, n=2 with COPD patients, n=2 with mixed population) (Table 1).

Most studies (n=31, 32%) reported changes in physiological parameters, which varied depending on the population observed, with 12 reporting BP values for patients with cardiovascular disease, 17 reporting HbA1c values for patients with diabetes, and two studies reporting multiple physiological values in mixed populations) (Table 1).

Hospital admission during the intervention was recorded in 28 studies (29%, n=21 with cardiovascular disease patients, n=4 with COPD patients, n=3 with mixed sample) and death was noted in 17 studies (18%, n=14 in patients with cardiovascular disease, n=2 in patients with COPD , n=1 with mixed population) (Table 1).

Quality of life pre- and post- intervention was recorded in 21 studies (22%, n=11 studies in patients with cardiovascular disease, two in patients with diabetes, six studies in patients with COPD, and two with mixed population) (Table 1).

Excluded studies

A total of 32 (25% of the total assessed for eligibility) studies [113-144] were excluded. A summary of these studies can be found in Supplementary Table 2. Most [n=18 (56% of the total excluded)] were excluded because they were not related to a telemonitoring intervention, two (6% of the total excluded) studies included disease populations not included in this review, 10 (31% of the total excluded) reported outcomes outside the scope of the review, one (3% of the total excluded) was a literature review, and one (3% of the total excluded) was a study protocol.

Risk of bias assessment

A summary of the risk of bias assessment for the included papers can be found in the Supplementary Tables 3, 4 and 5. Overall, most RCTs [48/66 (71%)] and non-RCTs [17/20 (84%)] included in this review showed either some concern or high risk of bias. Most RCT studies showed either some concerns or high risk of bias in the randomisation process as well as in the selection of reported results. Some RCTs showed either some concerns or high risk of bias in missing outcomes data. Few RCTs showed either some concern or high risk of bias in the measurement of the outcomes.

Most of the non-RCTs showed either some concerns or high risk of bias in the “bias due to confounding” category. Ten studies showed either some concerns or high risk of bias in the “bias in measurement of outcomes” category. Few of the non-RCTs showed either some concerns or high risk of bias in the “bias due to missing data” category as well as in the “bias due to deviations from the intended intervention” category.

Studies included in the meta-analyses were assessed for publication bias. Funnel plots and Egger test were performed only where 10 or more studies were available [145].

Funnel plots for the outcomes of Systolic Blood Pressure, HbA1c and Mortality can be found in the supplementary files (Supplementary Figure 6). The Egger test results revealed no evidence of publication bias for systolic blood pressure, HbA1c or mortality.

Ongoing Studies

The databases search did not return any protocols for on-going studies. Searches on clinicaltrials.gov (updated to 5 February 2021) identified 22 on-going studies[146-167] (n=14 with cardiovascular disease patients; n=4 with diabetes patients; n=4 with COPD patients), which are reported in details in Supplementary Table 7.

Primary Outcomes

Adherence

Adherence was assessed in 12 studies at different time-points: one-month (n=3) [54, 69, 87], six weeks (n=2) [61, 106], 2 months (n=1)[16], three months (n=1) [33], six months (n=4) [45, 51, 62, 95] and 12 months (n=1)[39]. Seven studies [16, 39, 45, 51, 61, 62, 95] demonstrated a benefit of telemonitoring on patient adherence when compared to a comparator whereas 4 [33, 54, 69, 87] showed no difference when compared to a comparator. One study [106] compared two telemonitoring systems and showed that

educational support combined to telemonitoring positively influences adherence compared to telemonitoring only. Due to variations in how adherence was defined in the studies, a meta-analysis was not performed. A summary of these studies is reported in Table 2.

Satisfaction

Patient satisfaction with the intervention was assessed in nine studies (n=2 with cardiovascular disease patients, n=3 with diabetic patients, n=2 with COPD patients, n=2 with mixed population) (Table 3). Five studies [25, 31, 45, 81, 94] demonstrated a benefit of telemonitoring on patient satisfaction when compared to a comparator whereas 4 [33, 46, 47, 98] showed no difference when compared to a comparator. Due to variation in how satisfaction was defined in the studies, a meta-analysis was not performed. A summary of these studies is provided in Table 3.

Secondary Outcomes

Quality of Life

Studies included in the meta-analyses were pooled by comparable scales (e.g. Short Form 36 - SF-36) and endpoints (e.g. 6- or 12-months), with 8 studies [19, 34, 36, 38, 50, 99, 104, 107] included in meta-analyses.

Four studies [19, 34, 38, 107] reported SF-36 scores (mental and physical) at comparable endpoints (12 months) and were included in the meta-analyses (Figure 2 sub-groups 1.1.1 and 1.1.2). From the meta-analysis, telemonitoring showed greater improvements compared to usual care on physical component scores (weighted mean difference (MD) 3.72, 95% CI 1.73 to 5.70, P=.0002, I^2=51%, Figure 2) compared to comparator, but no difference on mental component scores (weighted MD 1.06, 95% CI -0.12 to 2.25, P=.08, I^2=0%, Figure 3).

Two studies[99, 104] reported EuroQoL 5 Dimension (EQ-5D) scores at comparable endpoints (12 months) and were included in the meta-analysis (Figure 2 sub-group 1.1.3). There was no difference in quality of life between groups (weighted MD 0.01, 95% CI -0.04 to 0.06, *P=.71*, I^2=0%)

Two studies[36, 50] utilising the Minnesota Living with Heart Failure© Questionnaire (MLHFQ) overall scores at 3-months were included in the meta-analysis (Figure 2 sub-group 1.1.4), demonstrating that the telemonitoring group showed greater improvements on quality of life (weighted MD -7.42, 95% CI -13.45 to -1.39*, P=.02*, I^2=0%) compared to comparator.

Thirteen studies[23, 26, 39, 46, 61, 65, 68, 73, 95, 103, 106, 110, 111] could not be included in the meta-analysis, due to reporting different time-points and using different questionnaires to assess quality of life. Five studies reported a significant improvement in QoL in the telemonitoring group compared to usual care at 6-weeks [61], 6-months [95, 103], and 12-months [46] measured using a variety of questionnaires (MLHFQ [95], EQ-5D [46, 61], 15D [103]), whilst nine studies reported no difference in QoL between telemonitoring and usual care at 4-weeks [73], 6-weeks [68, 106], 7-weeks [73], 3-months [39], 6-months [26, 65, 110], 9-months [111], 12-months [39]. One study [23] reported significant improvement in QoL in the usual care group compared to telemonitoring at 2-months and at 6-months using the St. George's Respiratory Questionnaire (SGRQ).

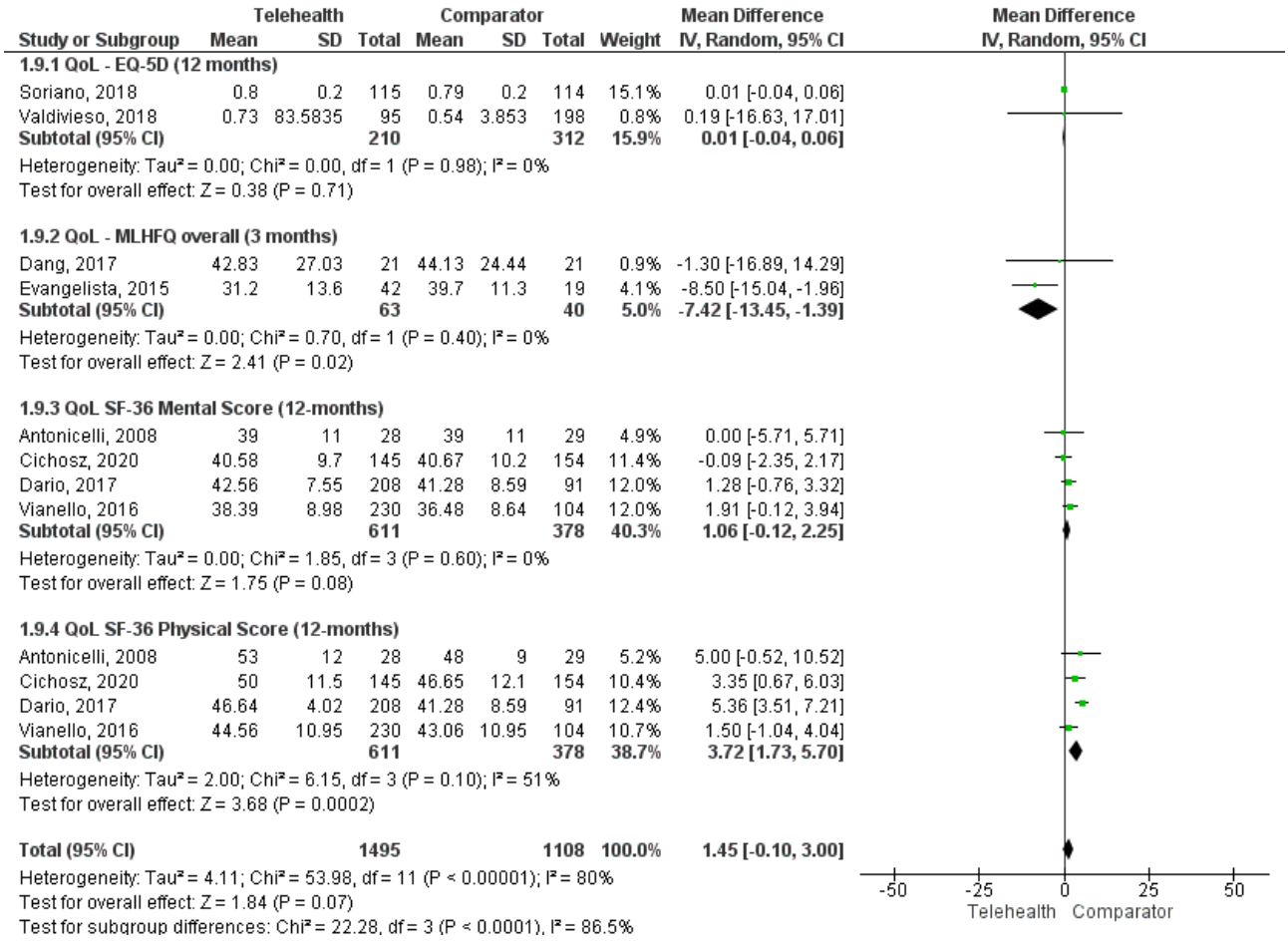

Figure 2. Impact of telemonitoring versus comparator on quality of life. 1.1.1 SF-36 mental component score; 1.9.1. EuroQoL 5 Dimension (EQ-5D).; 1.9.2 Minnesota Living with Heart Failure© Questionnaire (MLHFQ); 1.9.3 Short Form 36 (SF-36) mental score; and 1.9.4 SF-36 physical component.

Mortality

Meta-analyses for mortality were conducted at 6-months and 12-months follow-up (Figure 3). Sensitivity analyses were conducted at 6- and 12-months follow-up with removal of studies at high-risk of bias, and at 12-months removing non-RCTs (Supplementary Figure 1). Sensitivity analysis with removal of non-RCTs at 6-months was not conducted as all studies included were RCTs.

A total of 11 studies contributed to the all-cause mortality meta-analysis; 4 studies [42, 53, 87, 110] (n=2,056) provided data at 6-months and 7 studies[19, 43, 64, 67, 99, 104, 108] (n=2,578) provided data at 12-months. There was no significant difference in all-cause mortality between telemonitoring and comparator at 6-months (RR 0.86, 95% CI 0.68 to 1.07, *P=.18*, I^2=35%, Figure 3). This finding was consistent when studies evaluated as high risk of bias were removed (Supplementary Figure 1). There was a significantly lower risk of all-cause mortality with telemonitoring compared to comparator at 12-months (RR 0.71, 95% CI 0.56 to 0.89, *P=.003*, I^2=0%; Figure 3). This finding was consistent following the removal of non-RCTs and studies evaluated as high risk of bias (Supplementary Figure 1).

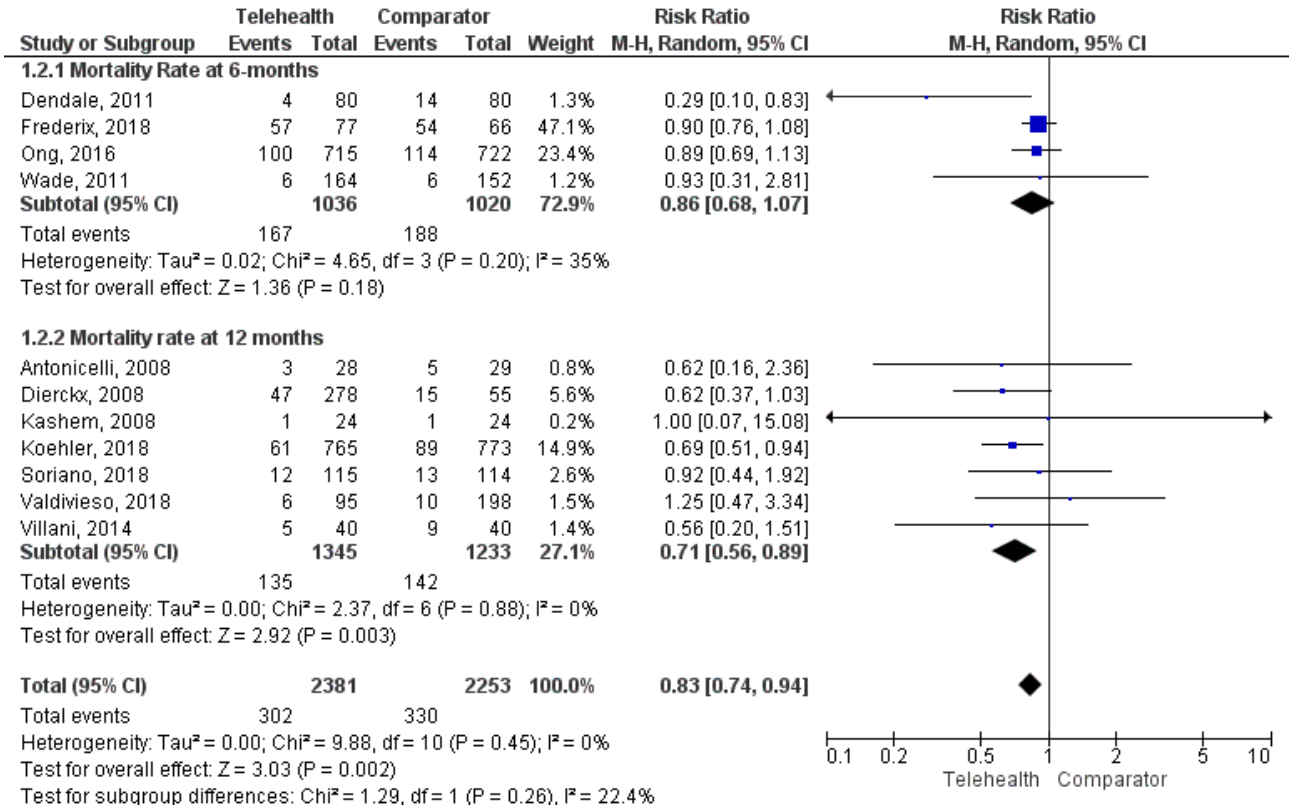

Figure 3. Impact of telemonitoring versus comparator on the mortality rate at 6 and 12-month. Mortara et al.(82) was not included in mortality meta-analyses due to use of a composite outcome of mortality/hospitalisation, where absolute mortality results were not

available. Seto et al.(94) was not included in mortality meta-analyses due to zero events in the control group.

Hospitalisation

Meta-analyses for hospitalisation at 6-months and 12-months follow-up were conducted (Figure 4), with sensitivity analyses removing studies classified as high risk of bias (Supplementary Figure 2) and a subgroup analysis including only studies with heart failure (12) patients. Subgroup analyses for studies with COPD and multiple chronic conditions were not possible due to lack of absolute values and/or no comparator [32, 88].

Eight studies contributed to the all-cause hospitalisation meta-analyses; 3 studies [26, 37, 86] (n=466) provided data at 6-months and 5 studies [28, 55, 83, 99, 104] (n=1,825) provided data at 12-months. There was no significant difference in the risk of all-cause hospitalisation between groups at 6-months (RR 1.09, 95% CI 0.85 to 1.40, P=.50, I^2=46%) or 12-months (RR 0.97, 95% CI 0.70 to 1.33, *P=.84*, I^2=79%) (Figure 4). This result was consistent also after the removal of studies evaluated as high risk of bias (Supplementary Figure 2). The meta-analysis that included only patients with heart failure showed no difference between groups in the risk of hospitalisation between the telemonitoring and comparator groups (RR 0.99, 95% CI 0.81 to 1.22, *P=.94*, I^2=69%, Supplementary Figure 2).

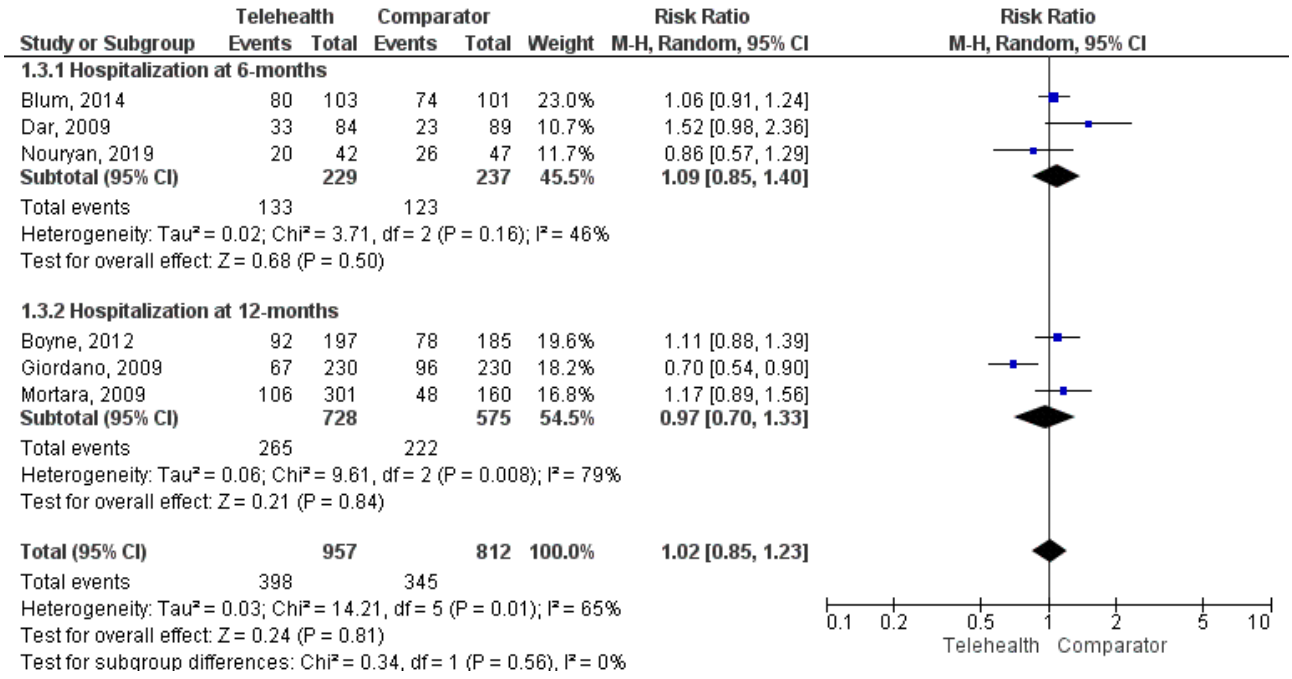

Figure 4. Impact of telemonitoring versus comparator on hospitalization at 6 and 12-months

Changes in Blood Pressure

Ten studies [19, 20, 27, 41, 48, 65, 75, 78, 80] reported on the change in SBP and eight [18, 20, 27, 48, 65, 75, 78, 80, 93] on DBP between a telemonitoring intervention and usual care and were included in the meta-analyses. Further details on analyses for blood pressure are provided in Supplementary File 1.

Systolic blood pressure

SBP was significantly reduced in the telemonitoring group (n=1477) compared to usual care (n=1484) (weighted MD –5.34 mmHg, 95% CI -7.81 to -2.86, *P<.0001*, I^2=100%, Figure 5). In the sub-group analysis according to study time-points, similar results were observed for SBP at 6 months (weighted MD -3.85 mmHg, 95% CI -7.03 to -0.68*, P=.02*, I^2= 100%, Figure 5) and at 12 months (weighted MD -3.85 mmHg, 95% CI -7.03 to -0.68*, P<.02*, I^2= 100%, Supplementary Figure 3) in favour of telemonitoring.

The sensitivity analysis, excluding studies where the SD was not reported directly [41, 48, 93], did not materially change the results [(weighted MD -5.19 mmHg, 95% CI -8.01 to -2.37, *P<.001*, I^2=100%); Supplementary Figure 3]. The sensitivity analysis was also performed excluding studies with high risk of Bias (Supplementary Figure 3); results remained in favour of telemonitoring (weighted MD-2.84 mmHg, 95% CI -4.22 to -1.46, *P<.001*, I^2=98%).

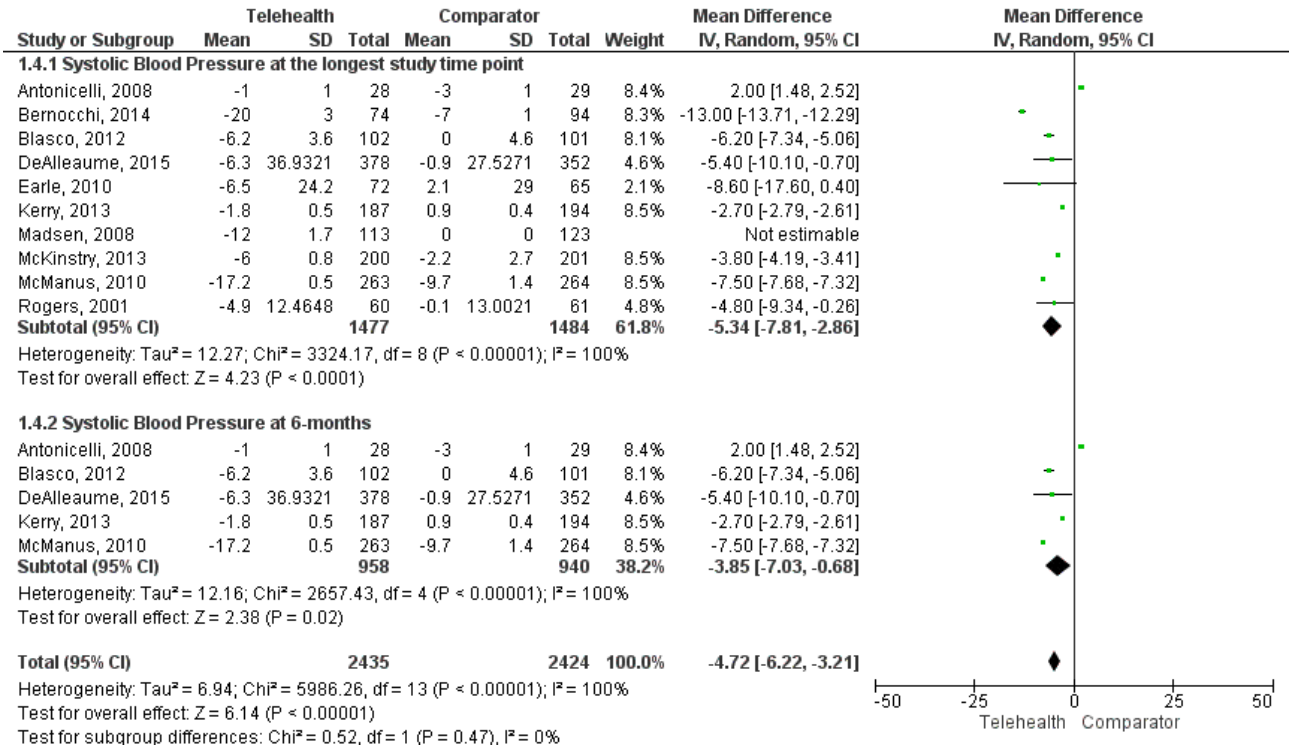

Figure 5. Impact of telemonitoring versus usual care on changes in systolic blood pressure (Mean Difference) at the longest study point and at 6-months.

Diastolic blood pressure

A meta-analysis including the longest time-point, demonstrated a significant reduction in DBP in favour of telemonitoring (n=1218) compared to comparator (n=1255) (weighted MD –2.83 mmHg, 95% CI -3.98 to -1.68, P< .001, I^2= 99%, Supplementary Figure 4). In the sub-group analysis, a similar result was observed for DBP reduction at 6 months (weighted MD -5.44 mmHg, 95% CI -9.00 to -1.87, *P=.003*, I^2= 100%, Supplementary Figure 4) in favour of

telemonitoring, but not for DBP at 12 months (weighted MD -1.09 mmHg, 95% CI -4.76 to 2.57, *P=.56*, I^2= 97%, Supplementary Figure 4). Sensitivity analyses at the longest time point excluding studies with high risk of bias (Supplementary Figure 4), showed no significant reduction in DBP in the telemonitoring group (weighted MD –1.07 mmHg, 95% CI -2.58 to 0.44, *P=.16*, I^2=98%) compared to usual care.

Changes in HbA1c

Eighteen studies reported on HbA1c and all studies compared telemonitoring to usual care, with 11 studies (n=3,277) included in the meta-analysis[30, 33, 38, 49, 52, 61, 66, 90, 92, 97, 112]. Further details on the excluded studies for meta-analysis are provided in Supplementary File 2.

Duration of the pre- and post-interval varied with two studies reporting 6-week assessment[61, 90], five [30, 33, 49, 52, 66] with 3-months assessments, one with 9-months [112], and three [38, 92] with 12-months. Sensitivity analysis was performed excluding studies with high risk of bias [61, 97].

The overall mean change in HbA1c is shown in Supplementary Figure 5. The pooled estimate showed a reduction in mean change in HBA1c in the telemonitoring group (n=1703) (weighted MD -0.33, 95% CI -0.57 to -0.09, *P= .008*, I^2= 99%, Supplementary Figure 5). The result did not materially change after sensitivity analysis removing studies at high risk of bias [61, 90] (Supplementary Figure 5). Subgroup analyses according to study time points show no significant difference in the change in HBA1c values between telemonitoring and comparator (Supplementary Figure 5).

DISCUSSION

Main Findings

Our results suggest that telemonitoring interventions are associated with good patient adherence and satisfaction. Although this review did not demonstrate improvements in quality of life with telemonitoring, there was evidence to suggest reductions in all-cause mortality and improvements in blood pressure and blood glucose control. Conversely, there was evidence to suggest telemonitoring interventions may be associated with a higher rate of hospitalisations, which could be interpreted as a positive role of telemonitoring in detecting patients' health issues more than usual care.

Comparison to Prior Work

Our review has shown improvements in physiological parameters (blood pressure and blood glucose) for patients receiving telemonitoring interventions. These findings demonstrate the positive role of telemonitoring in improving patients' self-management of their condition(s). This is in line with other reviews that have shown similar improvement in hypertension [168] and type 2 diabetes [169] self-management after telemonitoring interventions.

The studies included in this review consistently showed patients receiving telemonitoring interventions had lower all-cause mortality compared to patients receiving usual care. A recent umbrella review [170] examining the effects of telemonitoring on mortality in several clinical populations (cardiovascular, COPD, neurological) reported similar findings for the cardiovascular population, where the mortality rate was either reduced in the telemedicine users or remained unchanged compared to usual care. The same review [170] did not find any difference in mortality between telemonitoring and usual care in patients with COPD. The impact on death is an important outcome when considering the administration of

remote interventions over in-person visits, and the reduced mortality rate with telemonitoring reported by our review suggests the effectiveness of telemonitoring for patients with chronic conditions.

Surprisingly, the overall results of our review have shown a higher risk of hospitalisation among patients undergoing telemonitoring intervention. There is inconsistency in previous literature on the role that telemonitoring has in reducing the risk of re-hospitalisation, with some studies reporting no differences compared with usual care [171], whilst others conclude that telemonitoring is an effective tool to reduce all-cause hospitalisation in adults with heart failure [172]. Thurmond et al [173] noted the importance that the type of telemonitoring intervention has on its acceptability by patients and consequently their adherence to it, which when poor, may influence the rate of re-hospitalisation. This would suggest the need to identify common characteristics for effective telemonitoring interventions (or 'active ingredients') that facilitate patient acceptability. It may also be possible that increased hospitalisations with telemonitoring is a positive finding, i.e., reasons for hospitalisation may be identified earlier by telemonitoring and initiate hospitalization, compared to usual care, averting serious outcomes and death. Hypothetically, this could have contributed to the reduced mortality at 12-months, however, future research is needed to substantiate this.

The results of this review are in line with the results from previous systematic reviews assessing patient satisfaction with telemonitoring interventions [174, 175]. From qualitative reports, the convenience in decreased travel time and costs, and the reassurance of being monitored, are the most likely reasons for patients preferring telemonitoring over usual care [176]. It is important to note that patient satisfaction may differ with the type of

telemonitoring device used; indeed available evidence suggests higher patient satisfaction is reported for videoconferences and devices which allow automated data transmissions [174].

The included studies did not report significant improvements in the quality of life for patients receiving a telemonitoring intervention compared to usual care. Our findings confirm previous reviews[177, 178], whilst expanding the results to populations outside care-homes [178] and including study designs other than RCTs [177]. Although telemonitoring does not seem to improve quality of life compared to usual care, previous findings [178] have shown important benefits of telemonitoring in improving patient's confidence in accessing healthcare services.

Strengths and Limitations

This review included a strict definition of telemonitoring, only including studies that utilised a device to collect health measures and facilitated two-way communication/action between the patient and healthcare team. Despite the inclusion of studies with low methodological quality, sensitivity analyses were conducted where appropriate, reducing the potential of bias to impact the results of this review. The studies included in this review presented a wide-range of telemonitoring interventions which differed in the personnel involved, administration of the intervention, technology used, etc.; and that were examined in a variety of populations with different long-term conditions, making the results highly generalisable. Robust methodology was employed with independent screening and data extraction by two reviewers and risk of bias assessment in duplicate.

Several limitations are noteworthy. First, despite our initial plans to investigate the uptake, patient retention and satisfaction and associated factors, when using interactive remote patient monitoring devices to manage chronic health conditions, no studies reported uptake and retention outcomes and therefore these outcomes could not be reported. Most of the included studies assessed similar outcomes but used different measurement tools, thus making comparison difficult, particularly studies investigating patients' adherence [16, 33, 39, 45, 51, 54, 61, 62, 69, 87, 95, 106] and satisfaction [25, 31, 33, 45-47, 81, 94, 98] with the intervention. Second, despite our efforts to define the best search strategy to identify all relevant articles for our review, possible omission of papers due to the heterogeneity in key terms used by authors cannot be ruled out. We did not conduct any searches for grey literature. And third, most outcomes analysed in this review have been infrequently investigated in literature (e.g., mortality was reported only in 18% of the included studies; adherence in only 13% and satisfaction in only 9%), and further research is required to properly assess the effects of telemonitoring on these outcomes. Moreover, some conditions (e.g. COPD) were under-represented as few studies investigating the effects of telemonitoring interventions for these populations were available, thus we could not conduct a separate meta-analysis for each condition. The type and quality of usual care also varied throughout included studies, which may have influenced the results in favour of/against telemonitoring.

CONCLUSION

Telemonitoring is a promising tool to manage long-term conditions with the potential to reduce the associated costs and alleviate patient difficulties in accessing primary healthcare. Patient satisfaction and adherence with telemonitoring appear, overall, to be promising.

Although telemonitoring resulted in improvement in physiological parameters and reduced all-cause mortality compared to usual care, there was no improvement in quality of life and increased risk of hospitalisations with telemonitoring. Although the latter may a positive finding, indicating earlier detection of health issues and action (resulting in hospitalisation), this result warrants future investigation. Telemonitoring is expanding rapidly, more so since the COVID-19 pandemic, and has been shown to be a viable alternative to usual care for the management of patients with long-term health conditions.

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CONFLICT OF INTEREST

DGL, MC, and MI report no conflicts of interest. BJRB has received research funding from BMS/Pfizer. SLH has received an investigator-initiated grant from Bristol-Myers Squibb. GYHL has been a consultant and speaker for Bristol-Myers Squibb/Pfizer, Boehringer Ingelheim and Daiichi-Sankyo. No fees are received personally. DJW has been a consultant and speaker for Medtronic and Boston Scientific. DAL has received investigator-initiated educational grants from Bristol Myers Squibb (BMS); been a speaker for Boehringer Ingelheim, Bayer, and BMS/Pfizer and consulted for Boehringer Ingelheim, Bayer, and BMS/Pfizer; all outside the submitted work.

LIST OF ABBREVIATIONS

BP: Blood Pressure

CASP: Critical Appraisal Skills Programme

CENTRAL: Cochrane Central Register of Controlled Trials

CI: Confidence Interval

COPD: Chronic Obstructive Pulmonary Disease

DBP: Diastolic Blood Pressure

EQ-5D: EuroQoL 5 Dimension

GHQ: General Health Questionnaire

GP: General Practitioner

MD: Mean Difference

MLHFQ: Minnesota Living with Heart Failure© Questionnaire

PHQ: Physical Health Questionnaire

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses

PROSPERO: International Prospective Register of Systematic Reviews

QoL: Quality of Life

RCT: Randomized Controlled Trial

RevMan: Review Manager

RR: Risk Ratio

SBP: Systolic Blood Pressure

SD: Standard Deviation

SF-12: Short Form 12

SF-36: Short Form 36

SGRS: St George's Respiratory Scale

LIST OF FIGURES

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Table 1 – Summary of the Included studies

First author, Year, country	**Study population,** n, condition	**Intervention** n, mean (SD) age; % male	**Comparator** n, mean (SD) age; % male	**Outcomes**	**Follow-up**	**Impact of telemonitoring**
Randomised controlled trials						
Edmonds 1998 [47] Canada	N=35, Type 2 diabetes	N=16, mean age and gender percentage not reported mobile phone data transmission	N=19, mean age and gender percentage not reported Usual care	Adherence; Satisfaction	3 months	Further studies required
Rogers 2001 [93] USA	N=121 Hypertensive	N=60 62.6 (10.0); 43% Manual uploading of BP values on an online platform	N=61 60.3 (11.9); 58% Usual care	Changes in BP	2-3 months	+
Bergenstal 2005 [25] USA	N=47, Type 2 diabetes	N=24, M37%, mean age 44(17) years Automated data transmitted via modem	N=23, M39%, mean age 45(13) years Data transmitted via telephone	HbA1c; Satisfaction	4 weeks	+
Cleland 2005 [35] Germany	N=299 CHF	N=163 67 (13), M 45%, mean age 67(23) years, Home telemonitoring Automated data collection and transmission via dedicated device	Nurse telephone support N=170, 68(10) years, M73% Usual care N=85, 67(11) years, 82% Data transmission via telephone; Usual care	ACM	240 days	-

Shea 2006 [96], 2009 [97] USA	N=1665 Type 2 Diabetes	N=844, Gender percentage not specified, mean age 70(SD not specified) Manual upload of data on dedicated device/software	N=821, Gender percentage not specified, mean age 70(SD not specified) Usual care	BP, HBA1c%	12 months	+
Kashem 2008 [64] USA	N=48, HF	N=24, M72%, mean age 53(10) years Automated upload of data on dedicated device/software	N=24, M76%, mean age 54(10) Usual care	Mortality Hospitalization	12 months	=
Madsen 2008 [75] Denmark	N=136, Hypertension	N=113, M49%, mean age 55(11.7) years Automated upload of data on dedicated device/software	N=123, M52%, mean age 56.7(11.6) years Usual care	BP	6 months	=
Cho 2009 [33] South Korea	N=69, Type 2 diabetes	N=35, M26%, mean age 51.1(13.1) years Mobile App	N=34, M26%, mean age 51.1(13.1) years Online telemonitoring system	HbA1c %; Satisfaction ; Adherence	3 months	=
Dar 2009 [37] UK	N=299, CHF	N=84, M74%, mean age 72(12) years Automated upload of data on	N=89, M66%, mean age 72(12) years Usual care	No. of non-elective hospitalization; No. of HF related admissions	6 months	=

		dedicated device/software				
Giordano 2009 [55] Italy	N=460, CHF	N=230, M93%, mean age 57(10) Automated upload of data on dedicated device/software	N=230, M94%, mean age 57(10) Usual care	No. of HF hospitalization	12 months	+
Istepanian 2009 [60] UK	N=137, Type 2 diabetes	N=72, gender percentage not specified, mean age 60(12) Automated upload of data on dedicated device/software	N=65, gender percentage not specified, mean age 57(13) Usual care	HbA1c	9 months	Not clear
Mortara 2009 [83] UK	N=461, CHF	N=301, gender percentage not specified, mean age 60(12) Divided as follows: (i)N=106 monthly telephone contact; (ii)N=94 monthly telephone contact + data transmission; (iii)N=101 as (ii)+24h cardiorespiratory recording	N=160, gender percentage not specified, mean age 60(12) Usual care	ACH; Comp endpoint no. cardiac death and no. HF hospitalization	12 months	+

		Answering machine + nurse telephone support + weekly data transmission				
Earle 2010 [48] UK	N=137, Type 2 diabetes and hypertension	N=72, gender percentage not specified, mean age 59.6(12) years Automated upload of data on dedicated device/software	N=65, gender percentage not specified, mean age 57.1(13) years Usual care	BP	6 months	+
Lewis 2010 [73] UK	N=40, COPD	N=20, M50%, median age 70(61,73) Manual upload of data on dedicated device/software	N=20, M50%, median age 73(63,79) Usual care	QoL	6 months	=
McManus 2010 [80] UK	N=527, Hypertension	N=263, M47%, mean age 66.2(8.8) years Automated upload of data on dedicated device/software	N=264, M47%, mean age 66.2(8.8) years Usual care	BP	6 months	+
Bujnowska-Fedak 2011 [30] Poland	N=100, Type 2 diabetes	N=50, 52%, mean age 53.1(25.2) years Manual upload of data on dedicated	N=50, M50%, mean age 57.5(27.4) years Usual care	HbA1c	3 months	+

		device/software				
Dendale 2011 [42] Belgium	N=160, CHF	N=80, M62%, mean age 76(10) years Manual upload of data on dedicated device/software	N=80, M67%, mean age 76(10) Usual care	ACM; No. Heart failure hospitalization; No. of hospitalization	6 months	+
Konstam 2011 [68] USA	N=88, HF	N=44, M59%, mean age 71.7(12) years Manual upload of data on dedicated device/software	N=44, M68%, mean age 67(13.1) years Usual care	QoL (MLHFQ)	6 weeks	=
Neumann 2011 [84] Germany	N=60, Hypertension	N=30, M43%, mean age 54.7(17.4) years Automated upload of data on dedicated device/software	N=30, M53%, mean age 56.2(17.4) years Usual care	BP (24h)	3 months	+
Wade 2011 [110] USA	N=316, CHF	N=164, M51%, mean age 78.1 (SD not reported) Automated upload of data on dedicated device/software	N=152, M53%, mean age 78.1(SD not reported) Usual care	Mortality; QoL No. cardiovascular related hospitalization	6 months	=
Blasco 2012 [27] Spain	N=203, Acute Coronary Syndrome	N=102, M81%, mean age 60.6(11.5) years	N=101, M79%, mean age 61(12.1) years Usual care	BP	12 months	+

		Manual transmission of data via mobile phone				
Boyne 2012 [28] Netherlands	N=328, CHF	N=197, M58%, mean age 71(11) years Telephone support + usual care	N=185, M60%, mean age 71(11) years Usual care	No. HF hospitalization; No. cardiovascular related hospitalization	12 months	Further studies required
Dinesen 2012 [44] Denmark	N=111, COPD	N=61, gender percentage not reported, median age 68(45,82) years Manual upload of data on dedicated device/software	N=51, gender percentage not reported, median age 68(45,82) years Usual care	No. of hospital admissions	10 months	+
Seto 2012 [95] Canada	N=100, CHF	N=50, M82%, mean age 55.1(13.7) years Automated upload of data on dedicated device/software	N=50, M76%, mean age 52.3(13.7) years Usual care	QoL(MLHFQ); No. of hospitalization; Mortality rate; Adherence	6 months	+
De San Miguel 2013 [40] Australia	N=71, COPD	N=35, M57%, mean age 74(SD not reported) years Automatic upload of data on dedicated device/software	N=36, M38%, mean age 71 (SD not reported) years Usual care	No. of hospitalization; BP	6 months	=
Kerry 2013 [65] UK	N=318, Hypertension	N=187, M59%, mean age	N=194, M56%, mean age 71.1(12.6) years	BP; QoL	6 months	=

		71.1(12.6) years Telephone support + manual data transmission	Usual care			
Madigan 2013 [74] USA	N=514, HF	N=54, M26%, mean age 75 (12.1) years Automated upload of data on dedicated device/software	N=45, M40%, mean age 74.7(11.3) years Usual care	No. of rehospitalizations	180 days	=
Margolis 2013 [76], 2018 [77] USA	N=450, Hypertension	N=228, M55%, mean age 61.1(12) years Automated upload of data on dedicated device/software	N=222, M55%, mean age 61.1(12) years Usual care	BP	6 months	+
McKinstry 2013 [78] UK	N=401, Hypertension	N=200, M59%, mean age 60.5(11.8) years	N=201, M60%, mean age 60.8(10.7) years	BP	6 months	+
Bentley 2014 [23] UK	N=63, COPD	N=32, M36%, mean age 66.6(10.5) years Automated upload of data on dedicated device/software	N=31, M36%, mean age 66.6(10.5) years Usual care	No. hospital admissions; QoL; Mortality	2 months	Further studies required
Blum 2014 [26] USA	N=203, CHF	N=102, gender percentage not specified, mean age 73(8) years	N=101, gender percentage not specified, mean age 72(10) years Usual care	No. of hospitalizations; QoL (SF36)	6 months	=

		Automated upload of data on dedicated device/software				
Pressman 2014 [90] USA	N=225, Type 2 diabetes	N=118, M62%, mean age 55.2(9.3) years Manual upload of data on dedicated device/software	N=107, M60% mean age 56.4(8.7) years Usual care	HbA1c; BP	6 weeks	=
Ralston 2014 [91] USA	N=778, Hypertension	N=261, M56%, mean age 59.8(8.6) years Blood pressure monitor + pharmacist support	Blood pressure monitor only N=259, M45%, mean age 59.8(8.3) years Usual care N=258, gender percentage and mean age not reported	BP	12 months	+
Villani 2014 [108] Italy	N=80, CHF	N=40, M75%, mean age 72(3) years Manual upload of data on dedicated device/software	N=40, M72%, mean age 72(3) years Usual care	Mortality rate; No. of hospitalization for HF; QoL(PHQ)	12 months	+
Vourinen 2014 [109] Finland	N=94, HF	N=47, M83%, mean age 58.3(11.6) years Manually upload of data on dedicated device/software	N=40, M83%, Mean age 57.9(11.9) years Usual care	No. of hospital admissions	6 months	=
Fountoulakis 2015 [52]	N=105, Type 2	N=70, M64%, mean age	N=35, M68%, mean age	HbA1c	3 months	+

Greece	diabetes	55.2(16.1) years Automated upload of data on dedicated device/software	55.4(16.1) years Usual care			
Greenwood 2015 [58] USA	N=90, Type 2 diabetes	N=45, M75%, mean age 58(11) years Manual upload of data on dedicated device/software	N=45, M79%, mean age 58(11) years Usual care	HbA1c	3 months	+
Varon 2015 [106] UK	N=534, AF	N=399, gender percentage not specified, mean age 63.1(12.6) Automated upload of data on dedicated device/software (device 1)	N=135, gender percentage not specified, mean age 63.1(12.6) Automated upload of data on dedicated device/software (device 2)	Compliance ; QoL (EQ-5D-3L)	6 weeks	+
Evans 2016 [51] USA	N=421, HF N=20, healthy	N=421, M46%, mean age 71.8(8.8) Disease group Automated upload of data on dedicated device/software	N=20, M50%, mean age 72.2(4.3) years Healthy group Automated upload of data on dedicated device/software	Adherence	6 months	+
Kardas 2016 [61] Poland	N=60, Type 2 diabetes	N=30, M57%, mean age 59.9(5.31) years Automated upload of	N=30, M63%, mean age 59(8.9) years Usual care	QoL; HbA1c; BP; Adherence	6 weeks	+

		data on dedicated device/software				
Ong 2016 [87] USA	N=1437, CHF	N=715, M53%, mean age 73 (SD not reported) years Automated upload of data on dedicated device/software	N=722, M53%, mean age 73 (SD not reported) years Usual care	ACM; ACH; QoL (MLHFQ); Adherence	1 month	=
Vianello 2016 [107] Italy	N=334, COPD	N=230, M72%, mean age 75.96(6.54) years Manual upload of data on dedicated device/software	N=104, M73%, mean age 76.48(6.16) years Usual care	QoL; No. hospital admissions	12 months	=
Wild 2016 [112] UK	N=321, Type 2 diabetes	N=160, M66%, mean age 61(9.8) years Automated upload of data on dedicated device/software	N=161, M67%, mean age 61(9.8) years Usual care	HbA1c; BP	9 months	+
Baron 2017 [21], 2017b [22] UK	N=81, Type 2 diabetes	N=45, M69%, mean age 58.2(13.6) years Automated upload of data on dedicated device/software	N=36, M43%, mean age 55.6(13.8) years Usual care	HbA1c; BP	9 months	=

Beran 2018 [24] USA	N=450, Hypertension	N=228, M55%, mean age 61.1(12) years Automated upload of data on dedicated device/software	N=222, M55%, mean age 61.1(12) years Usual care	BP	6 months	+
Dang 2017 [36] USA	N=61, CHF	N=42, M64%, mean age 55(9.8) years Questionnaires via mobile phone	N=19, M64%, mean age 55(9.8) years Usual care	QoL (MLHFQ; GHQ)	3 months	+
Dario 2017 [38] Italy	N=299, Type 2 diabetes	N=208, M57%, mean age 73(5.8) years Manual upload of data on dedicated device/software	N=91, M53%, mean age 73(5.3) years Usual care	QoL (SF-36); HbA1c	12 months	Further studies required
Egede 2017 [49] USA	N=113, Type 2 diabetes	N=54, M19%, mean age 54.2(11) years Manual upload of data on dedicated device/software	N=59, M91%, mean age 54.2(11) years Usual care	HbA1c	3 months	+
Gallagher 2017 [54] USA	N=40, HF	N=20, M75%, median age 86(50,77) Automated upload of data on dedicated device/softw	N=20, M75%, median age 86(50,77) Usual care	Adherence; No. of hospital readmissions	1 month	+

		are				
Frederix 2018 [53] Belgium	N=142, CHF	N=77, M64%, mean age 76(10) years Manual upload of data on dedicated device/software	N=66, M67%, mean age 76(10) years Usual care	ACM	6 months	=
Koehler 2018 [67] Germany	N=1571, CHF	N=765, M70%, mean age 70(10) years Manual upload of data on dedicated device/software	N=773, 69%, mean age 70(10) years Usual care	ACM; Cardiovascular mortality	12 months	+
Kotooka 2018 [69] Japan	N=183, CHF	N=93, M55%, mean age 67.1(12.8) years Automated upload of data on dedicated device/software	N=91, M61%, mean age 65.4(15.6) years Usual care	ACM; Cardiovascular mortality; ACH; Cardiovascular rehospitalization; Adherence	1 month	=
Soriano 2018 [99] Spain	N=229, COPD	N=115, M80%, mean age 71(8) years Automated upload of data on dedicated device/software	N=114, M80%, mean age 71(8) years Usual care	ACM; ACH; QoL (EQ-5D)	12 months	=
Tupper 2018 [103] Denmark	N=281, COPD	N=141, M39%, mean age 69.8(9) years Manual upload of	N=140, M55%, mean age 69.4 (10) years Usual care	QoL (15D)	6 months	+

		data on dedicated device/software				
Valdivieso 2018 [104] Spain	N=427, Chronic conditions (COPD, type 2 diabetes, HF)	N=95, M71%, mean age 69.8(SD not reported) years Manual upload of data on dedicated device/software	N=179 Telephone support, M51%, mean age 75.9(SD not reported) years N=198, usual care, M54%, mean age 75.9(SD not reported) years	QoL (EQ-5D); Mortality; No. hospital admissions	12 months	+
Walker 2018 [111] Spain	N=312, COPD	N=154, M44%, median age 71 years (IQR not reported) Manual upload of data on dedicated device/software	N=158, M44%, median age 71 years (IQR not reported) Usual care	QoL (EQ-5D)	9 months	=
Nouryan 2019 [86] USA	N=98, HF	N=42, M32%, mean age 81.4 (SD not reported) years Automated upload of data on dedicated device/software	N=47, M32%, mean age 84.9(SD not reported) years Usual care	No. of hospitalizations; QoL (MLHFQ)	6 months	+
Cichosz 2020 [34] Denmark	N=299, CHF	N=145, M57%, median age 70(59.5,77) years Disease specific questionnaires via tablet	N=154, M51%, median age 69(61,76) years Usual care	QoL (SF-36)	12 months	=

Non-randomised studies						
de Lusignan 2001 [39] UK	N=20, CHF	N=10, gender percentage not reported mean age 75.2(SD not reported) manual upload of data on dedicated device/software	N=10, gender percentage not reported mean age 75.2(SD not reported). Usual care	Adherence; QoL (GHQ)	12 months	+
Tsang 2001 [102] Hong Kong	N=19, Type 2 diabetes	N=10, M50%, mean age 30(9) years Electronic diary + health questionnaires	N=9, M70%, mean age (8) years Usual care	HbA1c	3 months	+
Schoenfeld 2004 [94] USA	N=59, CHF	N=59, M76%, mean age 64(14) years Manual upload of data on dedicated device/software	N/A	Satisfaction	7 days	+
Trudel 2007 [101] Canada	N=30, Type 2 diabetes and hypertension	N=30, mean age and gender not specified Mobile app acting as personal medical diary	N/A	BP	4 months	Further investigation required
Antonicelli 2008 [18], 2010 [19] Italy	N=57, CHF	N=28, M57%, mean age 78(7) Manual upload of data on dedicated device/software	N=29, M65%, mean age 78(7) Usual care	Comb rate of H&M; QoL; BP	12 months	+

Kim 2008 [66] South Korea	N=34, Type 2 diabetes	N=18, M50%, mean age 45.5(9.1) years Automated upload of data on dedicated device/software + SMS	N=16, M44%, mean age 48.5(8.0) years Usual care	HbA1c %	3 months	+
Rodriguez-Idigoras 2009 [92] Spain	N=328, Type 2 diabetes	N=116, M54%, mean age 63(no SD reported) Manual upload of data on dedicated device/software	N=167, M49%, 64(no SD reported) Usual care	HbA1c %	12 months	+
Sicotte 2011 [98] Canada	N=46, COPD	N=23, M57%, mean age 73.7(9.6) years Manual upload of data on dedicated device/software	N=23, M56%, mean age 75.4(9.7) years Usual care	Satisfaction ; QoL (SF-12)	3 months	=
Stuckey 2011 [100] Canada	N=24, Cardiovascular disease or Type 2 diabetes	N=24, M25%, mean age 56.6(8.9) years Manual upload of data on dedicated device/software	N/A	BP; Compliance	8 weeks	+
Chau 2012 [31] Hong Kong	N=40, COPD	N=22, 95%, mean age 73.5(6) years Manual upload of data on	N=18, M100%, mean age 72.2 (6) years Usual care	Satisfaction ; QoL (CRQ); No. of hospitalizations	2 months	+

		dedicated device/software				
Domingo 2012 [45] Spain	N=97, HF	N=46, M30%, mean age 66.5(11.5) years Automated upload of data on dedicated device/software	N=51, M30%, Mean age 66.5(11.5) years Usual care	Adherence; Satisfaction	6 months	+
Karg 2012 [62] Germany	N=36, COPD	N=36, M26%, mean age 67.9(6.9) years Automated upload of data on dedicated device/software	N/A	Adherence	6 months	+
Agboola 2013 [16] USA	N=30, Hypertension	N=15, M20%, mean age 61.9(SD not reported) years Web based device	N=15, M40%, mean age 61.6(SD not reported) years Mobile Blood pressure device	Adherence	2 months	+
Chen 2013 [32] Taiwan	N=141, Cardiovascular disease	N=141, M61%, median age 70.8(60.8, 78.3) years Automated upload of data on dedicated device/software	N/A	ACH	6 months	+

Bernocchi 2014 [20] Italy	N=168, Hypertension	N=74, M51%, mean age 59.7(12.5) years Automated upload of data on dedicated device/software	N=94, M53%, mean age 59.1(13.3) years Usual care	BP	2-4 months	+
Mira-Solves 2014 [81] Spain	N=410, Chronic conditions (Type 2 diabetes, hypertension, CHF, COPD)	N=410, M64%, mean age not reported Automated upload of data on dedicated device/software	N/A	Satisfaction	24 months	+
DeAlleaume 2015 [41] USA	N=1289, Hypertension	N=1289, M59%, mean age 60.3(SD not specified) years Automated upload of data on dedicated device/software	N/A	BP	12 months	+
Dierckx 2015 [43] UK	N=278, HF	N=278, M73%, mean age 71(12) years Automated upload of data on dedicated device/software	N/A	Mortality rate; Re-hospitalization rate	6 months	+
Evangelista 2015 [50] USA	N=42, HF	N=21, M48%, mean age 72.7(8.9) years Manual	N=21, M48%, mean age 72.7(8.9) years	QoL (MLHFQ)	3 months	+

		upload of data on dedicated device/software				
Hanley 2015 [59] UK	N=23, Type 2 diabetes	N=23, M70%, mean age 60 years (SD not reported) Automated upload of data on dedicated device/software	N/A	Qualitative (motivation to self-monitoring and acceptability of intervention)	12 months	+
Donate-Martinez 2016 [46] Spain	N=74, Chronic conditions (COPD, Type 2 diabetes, HF)	N=74, M66%, mean age 67.95(11.14) years Manual upload of data on dedicated device/software	N/A	Satisfaction ; QoL	12 months	=
Grady 2016 [56] UK	N=40, Type 1 and 2 diabetes	N=40, M55%, median age 49.3(24,70) Manual upload of data on dedicated device/software	N/A	HbA1c	3 months	+
Amir 2017 [17] Israel	N=50, HF	N=50, M62%, mean age 73.8(10.3) years Automated upload of data on dedicated device/software	N/A	No. of HF related hospitalizations	3 months	+

Nissen 2017 [85] Denmark	N=14, COPD	N=14, M43%, mean age 69.5 years (SD not reported) Manual readings via telephone	N/A	Qualitative (patients' experience of the intervention)	6 months	+
Orozco-Beltran 2017 [88] Spain	N=521, Chronic conditions (COPD, type 2 diabetes, HF)	N=521, M61%, mean age 70(10.3) years Manual upload of data on dedicated device/software	N/A	HbA1c; BP; No. of hospital admissions	12 months	+
Lee 2018 [71] UK	N=10, Type 2 diabetes	N=10, M20%, mean age 62.6 years (SD not reported). Manual upload of data on dedicated device/software	N/A	Qualitative (facilitating positive experience and acceptance of telemonitoring)	1.5 to 3.5 years	+
Lee 2019 [70] Malaysia	N=48, Type 2 diabetes	N=48, M56%, mean age 51.9 years (SD not reported) Manual upload of data on dedicated device/software	N/A	Qualitative (satisfaction and participants perception of telemonitoring)	Not reported	+

Michaud 2018 [79] USA	N=955, Type 2 diabetes	N=955, M45%, median age 60(19,81) years Manual upload of data on dedicated device/softw are	N/A	BP; HbA1c	3 months	+
Grant 2019 [57] UK	N=40, Hypertension	N=23, M45%, mean age not reported Manual upload of data on dedicated device/softw are	N=23, M45%, mean age not reported. Paper diary.	BP	6 months	+
van Berkel 2019 [105] UK	N=3562, Chronic conditions (COPD, type 2 diabetes, HF)	N=3562, gender percentage not reported, median age 66.5(66.1,66. 9) years Manual upload of data on dedicated device/softw are	N/A	No. hospital admissions	12 months	+
Buis 2020 [29] USA	N=15, Hypertension	N=15, M53%, mean age 52.2 (6.0) years Real time home blood pressure tracking app	N/A	BP	12 weeks	+
Leng Chow 2020 [72] Singapore	N=205, HF	N=150, M61%, mean age 57.9(12.3)	N=55, M58%, mean age 63.9(14.2) years	ACH; No. of HF related hospitalizat	12 months	=

		years Automated upload of data on dedicated device/software	Usual care + Telephone support	ions		
Pekmezaris 2020 [89] USA	N=12, Type 2 diabetes	N=12, gender percentage not reported, mean age not reported Manual upload of data on dedicated device/software	N/A	Qualitative (patients acceptability/usability of the device)	1 month	Several aspect of the intervention to be improved

ACH: all cause hospitalization; ACM: all-cause mortality; AF: atrial fibrillation; BP: blood pressure; CHF: congestive heart failure; CRQ: chronic respiratory questionnaire; EQ-5D: EuroQoL 5 Dimension; GHQ: general health questionnaire; H&M: hospitalization and mortality; HF: heart failure; MLHFQ: Minnesota living with heart failure© questionnaire; PHQ: physical health questionnaire; QoL: quality of life; SF-12: Short-form 12; SF-36: short form 36; SGRQ: St George's respiratory questionnaire

*** + positive impact of telemonitoring over comparator; - negative impact of telemonitoring over comparator; = no differences between telemonitoring and usual care*

Table 2: Studies examining the impact of telemonitoring interventions vs comparator on Adherence

First author, Year, country	**Study population,** n, condition	**Intervention** n, % male; mean (SD) age	**Comparator** n, mean (SD) age; % male	**Outcomes**	**Follow-up**	**Impact of telemonitoring**
Randomised controlled trials						
1 month						
Ong 2016 [86] USA	N=1437, CHF	N=715, M53%, mean age 73 (SD not reported) years Automated upload of data on dedicated device/software	N=722, M53%, mean age 73 (SD not reported) years Usual care	Adherence, Electronically recorded, 82.7%	1 month	=
Gallagher 2017 [53] USA	N=40, HF	N=20, M75% median age 68(IQR 49-79) years Manual upload of data on dedicated device/software	N=20, M75%, median age 62 (IQR 52-75) years Usual care	Adherence Recorded electronically, 81% in both groups	1 month	=
Kotooka 2018 [68] Japan	N=183, CHF	N=93, M55%, mean age 67.1(12.8) years Automated upload of data on dedicated device/software	N=91, M61%, mean age 65.4(15.6) years Usual care	Adherence Recorded electronically, 90% at 12-month	12 months	=
6 weeks						
Varon 2015 [105] UK	N=534, HF	N=135, gender distribution not reported, mean age 69.1(12.6) years Docobo system (telemonitoring only)	N=399, gender distribution not reported, mean age 69.1(12.6) years Motiva system (telemonitoring+ educational videos)	Adherence, Assessed by the number of missing data during the telemonitoring period.	6 weeks	-
Kardas 2016 [60] Poland	N=60, Type 2 diabetes	N=30, M57%, mean age 59.9(5.31) years	N=30, M63%, mean age 59(8.9) years	Adherence, Expressed as medication taken vs	6 weeks	+

		Automated upload of data on dedicated device/software	Usual care	medication prescribed. 92.9%		
3 months						
Cho 2009 [32] South Korea	N=69, Type 2 diabetes	N=35, M26%, mean age 51.1(13.1) years Mobile App	N=34, M26%, mean age 51.1(13.1) years Online telemonitoring system	Adherence, Self-report, >70% in both groups	3 months	=
6 months						
Seto 2012 [94] Canada	N=100, CHF	N=50, M82%, mean age 55.1(13.7) years Automated upload of data on dedicated device/software	N=50, M76%, mean age 52.3(13.7) years Usual care	Adherence, Registered electronically, 80%	6 months	+
Evans 2016 [50] USA	N=421, HF N=20, healthy	N=421, M46%, mean age 71.8(8.8) Disease group Automated upload of data on dedicated device/software	N=20, M50%, mean age 72.2(4.3) years Healthy group Automated upload of data on dedicated device/software	Adherence, Checking the number of data against the participant's time spent in the study, Between 71-81%	6 months	+
Non-randomised studies						
2 months						
Agboola 2013 [15] USA	N=30, Hypertension	N=15, M20%, mean age 61.9(SD not reported) years Web based device	N=15, M40%, mean age 61.6(SD not reported) years Mobile Blood pressure device	Adherence, Electronically recorded based on frequency of data transmission.	2 months	+
6 months						
Domingo 2012 [44] Spain	N=97, HF	N=46, M30%, mean age 66.5(11.5) years Automated upload of data on dedicated device/software	N=51, M30%, Mean age 66.5(11.5) years Usual care	Adherence, Based on the number of educational videos watched. Between 67-85%	6 months	+

Karg 2012 [61] Germany	N=36, COPD	N=36, M26%, mean age 67.9(6.9) years Automated upload of data on dedicated device/software	N/A	Adherence, Usage of the device for at least 2/3 of working days, Full compliance	6 months	+
12 months						
de Lusignan 2001 [38] UK	N=20, CHF	N=10, gender percentage not reported mean age 75.2(SD not reported) manual upload of data on dedicated device/software	N=10, gender percentage not reported mean age 75.2(SD not reported). Usual care	Adherence, Based on the frequency of the uploaded data, 90%	12 months	+

CHF: congestive heart failure; HF: heart failure

*** + positive impact of telemonitoring over comparator; - negative impact of telemonitoring over comparator; = no differences between telemonitoring and usual care*

Table 3: Studies examining the impact of telemonitoring interventions vs comparator on satisfaction

First author, Year, country	**Study population**, n, condition	**Intervention** n, % male; mean (SD) age	**Comparator** n, % male; mean (SD) age	**Outcomes**	**Follow-up**	**Impact of telemonitoring**
Randomised controlled trials						
4 weeks						
Bergenstal 2005 [24] USA	N=47, Type 2 diabetes	N=24, M37%, mean age 44(17) years Automated data transmitted via modem	N=23, M39%, mean age 45(13) years Data transmitted via telephone	Satisfaction, 5 points questionnaire, 4.30 in the phone group; 4.52 in the modem group	4 weeks	=
2 months						
Chau 2012 [30] Hong Kong	N=40, COPD	N=22, 95%, mean age 73.5(6) years Manual upload of data on dedicated device/software	N=18, M100%, mean age 72.2 (6) years Usual care	Satisfaction, 10-item questionnaire based on a 5-point system, 91%	2 months	+
3 months						
Edmonds 1998 [46] Canada	N=35, Type 2 diabetes	N=16, mean age and gender percentage not reported mobile phone data transmission	N=19, mean age and gender percentage not reported Usual care	Satisfaction, Patient questionnaire	3 months	Further studies required
Cho 2009 [32] South Korea	N=69, Type 2 diabetes	N=35, M26%, mean age 51.1(13.1) years Mobile App	N=34, M26%, mean age 51.1(13.1) years Online telemonitoring system	Satisfaction, Questionnaire, Internet vs. phone: 81% vs. 79%	3 months	=
Sicotte 2011 [97] Canada	N=46, COPD	N=23, M57%, mean age 73.7(9.6) years Manual upload of data on dedicated	N=23, M56%, mean age 75.4(9.7) years Usual care	Satisfaction, 5-point questionnaire, 4.50 score	3 months	=

		device/software				
6 months						
Domingo 2012 [44] Spain	N=97, HF	N=46, M30%, mean age 66.5(11.5) years Automated upload of data on dedicated device/software	N=51, M30%, Mean age 66.5(11.5) years Usual care	Satisfaction, 10-point questionnaire, 8.4 score	6 months	+
Non-randomised studies						
7 days						
Schoenfeld 2004 [93] USA	N=59, CHF	N=59, M76%, mean age 64(14) years Manual upload of data on dedicated device/software	N/A	Satisfaction, 3-point questionnaire, 98.1% indicating ease of use of the device	7 days	+
12 months						
Donate-Martinez 2016 [45] Spain	N=74, Chronic conditions (COPD, Type 2 diabetes, HF)	N=74, M66%, mean age 67.95(11.14) years Manual upload of data on dedicated device/software	N/A	Satisfaction, 11-item questionnaire with 10-point score, 8.63 score overall.	12 months	=
24 months						
Mira-Solves 2014 [80] Spain	N=410, Chronic conditions (Type 2 diabetes, hypertension, CHF, COPD)	N=410, M64%, mean age not reported Automated upload of data on dedicated device/software	N/A	Satisfaction, Questionnaire, 89.4% were satisfied with the ease of use.	24 months	+

CHF: congestive heart failure; HF: heart failure

*** + positive impact of telemonitoring over comparator; - negative impact of telemonitoring over comparator; = no differences between telemonitoring and usual care*