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Review Article

Remote Vital Sign Monitoring in Admission Avoidance Hospital at Home: A Systematic Review

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A B S T R A C T

Objectives: To examine randomized controlled trials (RCTs) of "hospital at home" (HAH) for admission avoidance in adults presenting with acute physical illness to identify the use of vital sign monitoring approaches and evidence for their effectiveness.
Design: Systematic review.
Setting and participants: This review compared strategies for vital sign monitoring in admission avoidance HAH for adults presenting with acute physical illness. Vital sign monitoring can support HAH acute multidisciplinary care by contributing to safety, determining requirement of further assessment, and guiding clinical decisions. There are a wide range of systems currently available, including reliable and automated continuous remote monitoring using wearable devices.
Methods: Eligible studies were identified through updated database and trial registries searches (March 2, 2016, to February 15, 2023), and existing systematic reviews. Risk of bias was assessed using the Cochrane risk of bias 2 tool. Random effects meta-analyses were performed, and narrative summaries provided stratified by vital sign monitoring approach.
Results: Twenty-one eligible RCTs (3459 participants) were identified. Two approaches to vital sign monitoring were characterized: manual and automated. Reporting was insufficient in the majority of studies for classification. For HAH compared to hospital care, 6-monthly mortality risk ratio (RR) was 0.94 (95% CI 0.78-1.12), 3-monthly readmission to hospital RR 1.02 (0.77-1.35), and length of stay mean difference 1.91 days (0.71-3.12). Readmission to hospital was reduced in the automated monitoring subgroup (RR 0.30 95% CI 0.11-0.86).
Conclusions and Implications: This review highlights gaps in the reporting and evidence base informing remote vital sign monitoring in alternatives to admission for acute illness, despite expanding implementation in clinical practice. Although continuous vital sign monitoring using wearable devices may offer added benefit, its use in existing RCTs is limited. Recommendations for the implementation and evaluation of remote monitoring in future clinical trials are proposed.

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Increasing population health needs and complexity continue to place greater demands on secondary care beds, services, and professionals.[1-3] In response, there has been a shift toward providing care outside of conventional, resource-intensive, inpatient settings.[4] One strategy is to treat acutely ill patients in their usual place of residence by providing access to health care professionals (through visits, supplemented by remote consultations), investigations, monitoring, and treatments traditionally provided in hospital.[5] Termed "hospital at home" (HAH), this approach can be defined by its intended purpose to either prevent admission (admission avoidance) or facilitate discharge from inpatient stay (early discharge).[6,7] Typically led by hospital teams, the design of these services varies depending on the range of conditions being managed, the skillset, and availability of staff and equipment. Managing acute illnesses at home to avoid admission has an equivalent risk of mortality and likelihood of readmission compared with hospital care and is positively experienced by patients.[7-10] Furthermore, the risks associated with hospitalization (infection, cognitive and functional decline, and venous thromboembolism) and costs can be reduced.[7,8,11-16]

A key component of inpatient care is the regular monitoring of vital signs—typically temperature, heart rate, blood pressure, respiratory rate, oxygen saturation, and consciousness.[17] These markers act as early predictors of negative outcomes prompting clinical intervention.[18,19] Although regular monitoring is a core element of HAH, its optimal nature has yet to be fully established. This includes what data are collected, at what frequency, whether it is continuous or episodic, who collects it, and the degree of remote access. Often, traditional and evidence-based hospital practices have therefore been translated into HAH models. For example, a health care professional may visit a patient to manually collect vital sign data at prespecified time intervals.[7] Alternatively, patients may be relied on to self-monitor to facilitate more effective allocation of limited clinical resources.[20] However, this introduces concerns regarding reliability of data collection particularly when patients are unwell.

Digital infrastructure has been developed in an attempt to address some of the challenges of acute HAH care. However, its implementation varies significantly between services.[21] Recent advances in technology have made it feasible to continuously monitor patients remotely using wearable devices that collect data on vital signs and additional variables (eg, physical activity).[22,23] Remote monitoring is being widely implemented by NHS England—termed a "virtual ward"—although the distinction between clinical care models associated with such monitoring is not clearly specified.[24-26] Automated monitoring using wearable devices such as a chest patch can provide continuous data on heart rate, respiratory rate, and movement. This requires minimal direct involvement from patients or clinicians (passive monitoring).[27-29] Additional devices directly used either by the patient or a carer, such as a pulse oximeter or a blood pressure monitor, can be intermittently applied to collect additional data (active monitoring).[27] Wearable sensors are considered accurate (eg, at detecting hypoxemia, or predicting impending readmission to hospital in heart failure patients) and acceptable (despite the potential limitations of restricting movement and comfort) and provide reassurance to patients and caregivers.[28-31] Furthermore, the ability to monitor patients' physical activity levels at home can provide insight into changes in functional status, as shown during recovery from hip fracture.[32]

In order to shape and continue to improve HAH care, it is important that the wide range of monitoring systems and the way they are being used are evaluated to identify their reliability and value for different clinical scenarios. It is known that remote "virtual ward" monitoring for early discharge reduces mortality and readmission rates in patients admitted with acute heart failure.[33] National Institute for Health and Care Excellence (NICE) have also recently provided recommendations on key features of remote monitoring technologies in virtual wards for acute respiratory infections, based primarily on observational studies of telehealth interventions.[34] However, research exploring this aspect of care in admission avoidance HAH is limited and insufficient to provide recommendations on standardizing key aspects of remote monitoring in this specific context. The potential use of these data as a marker of clinical status or to identify early deterioration is also yet to be determined. This systematic review aims to determine the extent to which remote monitoring is incorporated into existing HAH interventions for admission avoidance, examine the way that they were used, and identify the evidence for their effectiveness. To date, there are no studies that directly compare vital sign monitoring approaches within the same HAH intervention. RCTs comparing HAH to inpatient care for acute illness were therefore included and stratified by their remote monitoring approach.

Methods

This review has been reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.[35] The protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on February 23, 2023, registration number CRD42023372823.[36]

Eligibility Criteria

Randomized controlled trials of admission avoidance HAH involving adult patients presenting with an acute physical illness requiring admission were identified. Eligible RCTs compared an HAH for admission avoidance to standard inpatient hospital care. Study eligibility was not limited by outcomes or follow-up duration. There were no restrictions on language, year, or status of publication. Studies involving obstetric, end-of-life, mental health, and pediatric populations, and interventions targeted at end-of-life or long-term care, patient self-management of their condition at home, early discharge from hospital, or in outpatient settings were excluded. Systematic reviews, meta-analyses, quasi-experimental studies, abstracts, conference abstracts, opinion pieces, editorials, and case studies were excluded.

Information Sources, Search Strategy, and Selection Process

An updated search using a previously published search strategy was performed (Appendix 1).[7] The following databases were searched on February 15, 2023, for studies published since March 2, 2016: Cochrane Central Register of Controlled Trials (CENTRAL) (Cochrane Library, Wiley), MEDLINE (including Epub Ahead of Print and In-Process & Other Non-Indexed Citations) (OvidSP), Embase (OvidSP), CINAHL (EBSCOhost), and EconLit (ProQuest). International trial registries (who.int/ictrp and ClinicalTrials.gov) were searched using the terms "hospital at home" and "virtual ward" for ongoing RCTs (March 2, 2016, onward). Reference lists of relevant systematic reviews identified during scoping and database literature searches were examined. Forward and backward citation searches of all included studies were performed (Web of Science, search date February 15, 2023). Citations identified during the search strategy were imported into Rayyan systematic review manager software. Following deduplication, 2 authors (R.P., T.T.S.) independently screen all citations by title and abstract. Full-text articles for potentially relevant studies were obtained and independently screened for eligibility (R.P., T.T.S.). Reasons for exclusion were documented and discrepancies resolved through consensus discussion.

Table 1
Characteristics of Included Studies

Study	Characteristics
Caplan (1999)[40]	
Country	Australia
Study aim	To compare treatment of acute illness at home and in hospital, assessing safety, effect on geriatric complications, and patient/carer satisfaction
Type of RCT	Parallel RCT
Start and end date	October 1995 and February 1997
Participants	Patients requiring acute medical or surgical hospital admission; recruited from casualty
Number allocated	Intervention n = 51; control n = 49
Age, y, median (range)	Intervention 73 (17-111); control 79 (22-97)
Intervention	Admission avoidance HAH care provided by hospital community outreach team; clinical responsibility by GP or hospital doctor if GP declined
Follow-up period	1 and 6 mo
Outcomes	Geriatric complications (confusion, falls, urinary incontinence or retention, fecal incontinence or constipation, phlebitis, and pressure areas), patient/carer satisfaction, adverse events, and death
Corwin (2005)[41]	
Country	New Zealand
Study aim	To compare the efficacy, safety, and acceptability of treatment with intravenous antibiotics for cellulitis at home and in hospital
Type of RCT	Parallel RCT
Start and end date	July 2002 to June 2003
Participants	Patients with cellulitis requiring intravenous antibiotics; recruited from the ED
Number allocated	Intervention n = 98; control n = 96
Age, y, mean (SD)	Intervention 54.6 (20.6); control 48.4 (19)
Intervention	Admission avoidance HAH care provided by GP and community care nursing staff; run by an independent association of GPs in Christchurch (Pegasus Health)
Follow-up period	3 and 6 d
Outcomes	Advancement of cellulitis, readmission, days on IV antibiotics, functional outcomes (SF-36), patient satisfaction
Davies (2000)[42]	
Country	United Kingdom
Study aim	To compare HAH and hospital care as an inpatient in acute exacerbations of COPD
Type of RCT	Parallel RCT
Start and end date	February 1998 to August 1999
Participants	Patients with COPD presenting with an acute exacerbation requiring hospital admission; recruited from the ED
Number allocated	Intervention n = 100; control n = 50
Age, y, mean (SD)	Intervention 70 (8); control 70 (8)
Intervention	Admission avoidance HAH care provided by specialist outreach and district nurses; clinical responsibility for the patients remained with the hospital respiratory physicians
Follow-up period	14 d and 3 mo
Outcomes	Respiratory function, readmission, quality of life
Echevarria (2018)[43]	
Country	United Kingdom
Study aim	We have undertaken an RCT with an economic evaluation (cost-effectiveness analysis) comparing HAH with usual care in patients admitted with a low-risk exacerbation of COPD selected by DECAF score
Type of RCT	Parallel RCT
Start and end date	January 29, 2016, to December 2, 2016
Participants	Patients with COPD presenting with an acute exacerbation with a low risk of mortality (as determined by a DECAF score of 0 or 1); recruited from hospital, within 24 h of admission
Number allocated	Intervention n = 62; control n = 58
Age, y, mean (SD)	Intervention 71.0 (9.6); control 68.7 (10.5)
Intervention	Admission avoidance HAH care provided by the hospital respiratory multidisciplinary team
Follow-up period	90 d
Outcomes	Health and social costs
Harris (2005)[44]	
Country	New Zealand
Study aim	To compare the safety, electiveness, acceptability, and costs of a HAH program with usual acute hospital inpatient care.
Type of RCT	Parallel RCT
Start and end date	Not stated
Participants	Patients requiring inpatient admission for a variety of diagnoses; recruited from the ED or acute assessment ward area and in hospital for less than 36 hours (admission avoidance group)
Number allocated	Intervention n = 39; control n = 37
Age, y, mean (SD)	Intervention 80; control not stated
Intervention	Admission avoidance and early discharge HAH care provided by a hospital outreach program (Auckland Hospital); consultant geriatricians held clinical responsibility, in some cases shared with the patient's GP
Follow-up period	10, 30, and 90 d
Outcomes	Activities of daily living, cognitive function, instrumental activities of daily living; subgroup data not reported in citation, authors contacted May 2023 (no response), partial subgroup data available from published systematic review [Shepperd et al (2016)[7]]
Hernandez (2003)[45]	
Country	Spain
Study aim	To determine if home hospitalization with free patient phone access to a specialized nurse generates a better outcome at lower direct costs than inpatient hospitalization
Type of RCT	Parallel RCT
Start and end date	November 1, 1999, to November 1, 2000
Participants	Patients with COPD presenting with an acute exacerbation without criteria imperative for hospitalization; recruited from the emergency room

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Table 1 (*continued*)

Study	Characteristics
Number allocated	Intervention n = 121; control n = 101
Age, y, mean (SD)	Intervention 71.0 (9.9); control 70.5 (9.4)
Intervention	Admission avoidance HAH care provided by the respiratory specialist nurses and hospital respiratory physician if needed
Follow-up period	8 wk
Outcomes	Mortality, hospital readmission, ED visits, quality of life.
Kalra (2000)[46]	
Country	United Kingdom
Study aim	The objective of this study was to compare the efficacy of stroke unit, stroke team, and domiciliary stroke care in reducing mortality, dependence, and institutionalization in patients with moderately severe strokes
Type of RCT	Parallel RCT
Start and end date	April 1995 and October 1999
Participants	Patients presenting to hospital with an acute stroke (moderate severity); note that study design involved 3 groups with a comparison between stroke unit care, inpatient stroke team, and HAH; in this review, the inpatient stroke team was chosen as the control group, as this is considered most similar to the control groups of other studies
Number allocated	Intervention n = 153; control n = 152
Age, y, median (IQR)	Intervention 78 (16); control 75 (12)
Intervention	Admission avoidance domiciliary care provided by a multidisciplinary stroke team and community services
Follow-up period	3, 6, and 12 mo
Outcomes	Mortality, institutionalization, level of independence, activities of daily living, treatment inputs, readmission, hospital length of stay, cost
Levine (2018)[47]	
Country	USA
Study aim	Determine if home hospital care reduces cost while maintaining quality, safety, and patient experience
Type of RCT	Parallel RCT
Start and end date	September 12, 2016, and November 13, 2016
Participants	Patients requiring hospital admission with a diagnosis of infection, heart failure exacerbation, COPD exacerbation, or asthma exacerbation
Number allocated	Intervention n = 10; control n = 11
Age, y, median (IQR)	Intervention 65 (28); control 60 (29)
Intervention	Admission avoidance HAH care provided by hospital general internist, home health registered nurse, and additional multidisciplinary community services as needed
Follow-up period	30 d
Outcomes	Direct cost of the acute care episode, utilization, 30-d cost, physical activity, patient experience
Levine (2019)[48]	
Country	USA
Study aim	To compare outcomes of home hospital vs usual hospital care for patients requiring admission
Type of RCT	Parallel RCT
Start and end date	June 12, 2017, to February 17, 2018
Participants	Patients requiring hospital admission with a diagnosis of infection, heart failure exacerbation, COPD exacerbation, or asthma exacerbation
Number allocated	Intervention n = 43; control n = 48
Age, y, median (IQR)	Intervention 80 (19); control 72 (23)
Intervention	Admission avoidance HAH care provided by hospital general internist, home health registered nurse, and additional multidisciplinary community services as needed
Follow-up period	30 d
Outcomes	Direct cost of the acute care episode, utilization, 30-d cost, physical activity, patient experience
Mendoza (2009)[49]	
Country	Spain
Study aim	To compare the effectiveness and direct health care costs of treating elderly patients with decompensated heart failure using HAH care vs inpatient hospital care in a cardiology unit
Type of RCT	Parallel RCT
Start and end date	May 2006 to March 2007
Participants	Patients aged ≥65 years with heart failure (NYHA class II or III) presenting with an acute exacerbation; recruited from the ED
Number allocated	Intervention n = 37; control n = 34
Age, y, mean (SD)	Intervention 78.1 (6.2); control 79.9 (6.3)
Intervention	Admission avoidance HAH care provided by internal medicine specialist and a nurse (members of the staff of the HAH unit); Patients visited daily by specialist nurse and daily or alternate days by physician
Follow-up period	12 mo
Outcomes	Mortality, readmission, functional status, general health status, length of stay, costs
Nicholson (2001)[50]	
Country	Australia
Study aim	To compare the resource use and cost of acute care at home with inpatient care costs for acute COPD patients
Type of RCT	Parallel RCT
Start and end date	October 1999 to October 2000
Participants	Patient with COPD over 45 years, presenting with an acute exacerbation; recruited from primary care or ED
Number allocated	Intervention n = 13; control n = 12
Age	Not reported
Intervention	Admission avoidance HAH care provided by hospital specialist. Hospital maintained legal and financial responsibility; however, care also provided by GP, community nurses, and community services
Follow-up period	14 d
Outcomes	Cost to the health service
Patel (2008)[51]	
Country	Sweden
Study aim	To evaluate the feasibility of home care vs conventional care in relation to health-related quality of life and cost utility in patients with worsening congestive heart failure
Type of RCT	Parallel RCT
Start and end date	April 2004 and May 2006

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Table 1 (*continued*)

Study	Characteristics
Participants	Patients with a prior diagnosis of congestive heart failure assessed as being in need of hospital care by their consulting physician; recruited within 48 h after admission from the ED, heart failure outpatient clinic, or a medical ward
Number allocated	Intervention n = 13; control n = 18
Age, y, mean (SD)	Intervention 77 (10); control 78 (8)
Intervention	Admission avoidance HAH care provided by specialist nurses, using a written physician-directed care plan that included details of when to adjust medications; the nurses could consult a cardiologist if necessary
Follow-up period	12 mo
Outcomes	Clinical events, adverse events, health-related quality of life, total cost
Ricauda (2004)[52]	
Country	Italy
Study aim	To evaluate whether home treatment of elderly patients with acute uncomplicated first ischemic stroke is associated with different mortality rates and clinical outcomes from those of patients treated on a general medical ward (GMW)
Type of RCT	Parallel RCT
Start and end date	January 1997 to February 1998
Participants	Patients aged 70 y and older admitted to hospital with a diagnosis of acute ischemic stroke; recruited from the ED
Number allocated	Intervention n = 60; control n = 60
Age, y, median (IQR)	Intervention 83 (11); control 80 (13)
Intervention	Admission avoidance HAH 24-hour care provided by hospital multidisciplinary team consisting of hospital geriatrician, physiotherapist, occupational therapist, nurses, social worker, speech therapist, psychologist
Follow-up period	6 mo
Outcomes	Length of treatment, mortality, activities of daily living, functional impairment, depression, costs
Ricauda (2008)[53]	
Country	Italy
Study aim	To evaluate hospital readmission rates and mortality at 6-mo follow-up in selected elderly patients with acute exacerbation of COPD
Type of RCT	Parallel RCT
Start and end date	April 2004 to April 2005
Participants	Patients aged ≥75 y with a diagnosis of acute exacerbation of COPD admitted to hospital and requiring acute hospitalization; recruited from the ED
Number allocated	Intervention n = 52; control n = 52
Age, y, mean (SD)	Intervention 80.1 (3.2); control 79.2 (3.1)
Intervention	Admission avoidance HAH care provided by a regional hospital geriatric outreach home hospitalization service
Follow-up period	6 mo
Outcomes	Mortality, readmission, health status, satisfaction, residential care, length of stay, resource use and cost, caregiver outcomes
Richards (2005)[54]	
Country	New Zealand
Study aim	To determine whether community management of mild to moderate community-acquired pneumonia (CAP) is as effective and acceptable as standard hospital management of CAP
Type of RCT	Parallel RCT
Start and end date	July 2002 to October 2003
Participants	Patients presenting to hospital with CAP; recruited from the ED
Number allocated	Intervention n = 24; control n = 25
Age, y (mean)	Intervention 50.1; control 49.8
Intervention	Admission avoidance HAH care provided by GP and community care nursing staff; run by an independent association of GPs in Christchurch (Pegasus Health)
Follow-up period	2 and 6 wk
Outcomes	Median number of days to discharge, days of IV antibiotics, functional outcomes, mortality, readmission, patient satisfaction, costs
Shepperd (2021)[55]	
Country	United Kingdom
Study aim	To assess the clinical effectiveness of admission avoidance HAH with comprehensive geriatric assessment for older persons
Type of RCT	Parallel RCT
Start and end date	March 14, 2015, to September 10, 2019
Participants	Patients aged ≥65 y presenting to hospital requiring admission for a variety of diagnoses; recruited from home, ED, or short-stay acute medical ward
Number allocated	Intervention n = 700; control n = 355
Age, y (mean)	Intervention 50.1; control 49.8
Intervention	Admission avoidance HAH care with comprehensive geriatric assessment provided by attending geriatrician, nurse practitioners, physiotherapists and occupational therapists, social care, pharmacists, and GPs
Follow-up period	1, 6, and 12 mo
Outcomes	Living at home at 6 mo, new admission to long-term residential care, death, health status, delirium, patient satisfaction, quality-adjusted life years, resource use and costs at baseline and 6 mo; incremental cost-effectiveness ratios
Talcott (2011)[56]	
Country	USA
Study aim	Febrile neutropenia commonly complicates cancer chemotherapy; outpatient treatment may reduce costs and improve patient comfort but risk progression of undetected medical problems
Type of RCT	Parallel RCT
Start and end date	September 1994 and January 1999
Participants	Patients with post chemotherapy febrile neutropenia, assessed as low risk; recruited from outpatient setting
Number allocated	Intervention n = 47; control n = 66
Age, y, median (range)	Intervention 47 (25-74); control 47 (20-81)
Intervention	Admission avoidance HAH care provided by commercial home care provider; involving daily visits by a home care nurse using a protocol/standard checklist, hospital specialist assessment, and primary care physician if needed; home blood tests and intravenous antibiotics available
Follow-up period	Until resolution of symptoms or complications from acute episode
Outcomes	Major medical complications, readmission to hospital, quality of life, mean total charges

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Table 1 (*continued*)

Study	Characteristics
Tibaldi (2004)[57]	
Country	Italy
Study aim	To identify the benefits of the care in a Geriatric Home Hospitalization Service compared to a general medical ward in reducing behavioral disturbances in elderly patients with advanced dementia and in lowering caregiver's stress
Type of RCT	Parallel RCT
Start and end date	February 1999 and April 2002
Participants	Elderly patients with dementia requiring admission to hospital for an acute illness; recruited from the ED
Number allocated	Intervention n = 56; control n = 53
Age, y, mean (SD)	Intervention 82.9 (7.9); control 84.1 (7.5)
Intervention	Admission avoidance 24-h multidisciplinary geriatric home hospitalization service provided by regional hospital
Follow-up period	Until discharge
Outcomes	Behavioral disturbances, number of patients treated with antipsychotic drugs on admission and on discharge, mortality, length of stay, and place of discharge (home or to a nursing home)
Tibaldi (2009)[58]	
Country	Italy
Study aim	To evaluate the feasibility and effectiveness of a physician-led HAH service for selected elderly patients with acute decompensation of chronic heart failure
Type of RCT	Parallel RCT
Start and end date	April 1, 2004, to April 31, 2005
Participants	Patients aged ≥75 y with preexisting congestive heart failure requiring admission with acute decompensation; recruited from the ED
Number allocated	Intervention n = 48; control n = 53
Age, y, mean (SD)	Intervention 82.2 (5.2); control 80.1 (4.9)
Intervention	Admission avoidance 24-h multidisciplinary geriatric home hospitalization service provided by regional hospital, including geriatricians, nurses, physiotherapists, social workers, and counselors; hospitals maintained legal and financial responsibility
Follow-up period	6 mo
Outcomes	Mortality, readmission, length of stay, residential care, health status, psychological well-being
Vianello (2013)[59]	
Country	Italy
Study aim	To compare HAH and inpatient hospital care for neuromuscular disease patients with respiratory tract infections
Type of RCT	Parallel RCT
Start and end date	January 2009 to December 2011
Participants	Patients with NMD with respiratory tract infection and urgent need for hospitalization; recruited from the ED or specialist outpatient clinic
Number allocated	Intervention n = 26; control n = 27
Age, y, mean (SD)	Intervention 44.6 (20.4); control 46.7 (20.2)
Intervention	Admission avoidance HAH care provided respiratory therapists, district nurses, and caregivers; telephone access to respiratory specialists; home use of portable ventilator and training in assisting with coughing
Follow-up period	3 mo
Outcomes	Recovery from exacerbation defined as relief of respiratory distress and return of Spo_2 level
Wilson (1999)[60]	
Country	United Kingdom
Study aim	To compare effectiveness of patient care in HAH scheme with hospital care
Type of RCT	Parallel RCT
Start and end date	November 1995 and May 1997
Participants	Patients referred to the HAH scheme with an acute condition (variety of diagnoses); recruited from the community
Number allocated	Intervention n = 102; control n = 97
Age, y, median (IQR)	Intervention 84 (12); control 84 (12)
Intervention	Admission avoidance HAH care provided multidisciplinary team including nurses, therapy, generic health workers, and cultural link worker; general practitioner maintains medical responsibility
Follow-up period	3 d, 2 wk, 3 mo
Outcomes	Mortality, readmission, functional status, quality of life, patient satisfaction, costs

COPD, chronic obstructive pulmonary disease; DECAF, Dyspnea, Eosinopenia, Consolidation, Acidemia, and Atrial Fibrillation; ED, emergency department; GP, general practitioner; SF-36, 36-Item Short Form Health Survey.

Data Collection and Data Items

Following the identification of included articles, 2 authors (R.P., T.T.S.) independently extracted data using a standardized extraction form. Discrepancies were resolved through consensus discussion, involving additional authors as required (L.A., A.F.). For relevant unpublished data not reported in manuscripts, authors were contacted or data were extracted from existing systematic reviews. Descriptive data for participant characteristics and intervention design were collected. The TIDieR checklist and NICE guidance were used to characterize intervention remote monitoring components.[34,37] Data for all reported measures were collected and categorized into clinical (mortality, transfer to hospital, readmission to hospital, clinical complications, treatment efficacy, functional status and physical activity, mental health and cognitive status, and health-related quality of life) resource (length of stay, use of medication, use of investigations, health care professional interactions, contact with health care services, social care requirements, and cost), and user experience (patient satisfaction, relative or carer satisfaction, and clinician satisfaction) outcomes.

Study Risk of Bias Assessment

Two authors (R.P., T.T.S.) independently assessed the risk of bias of included studies using the Cochrane risk of bias 2 tool.[38]

Effect Measures and Synthesis Methods

Stratified random effects meta-analysis (subgroups classified by approach to vital sign monitoring) using individual patient data from trials was conducted for outcomes amenable to meaningful data synthesis (comparable measures collected and reported by 2 or more studies within each subgroup), using Review Manager 5.4. Outcomes were grouped to time points depending on study follow-up periods.

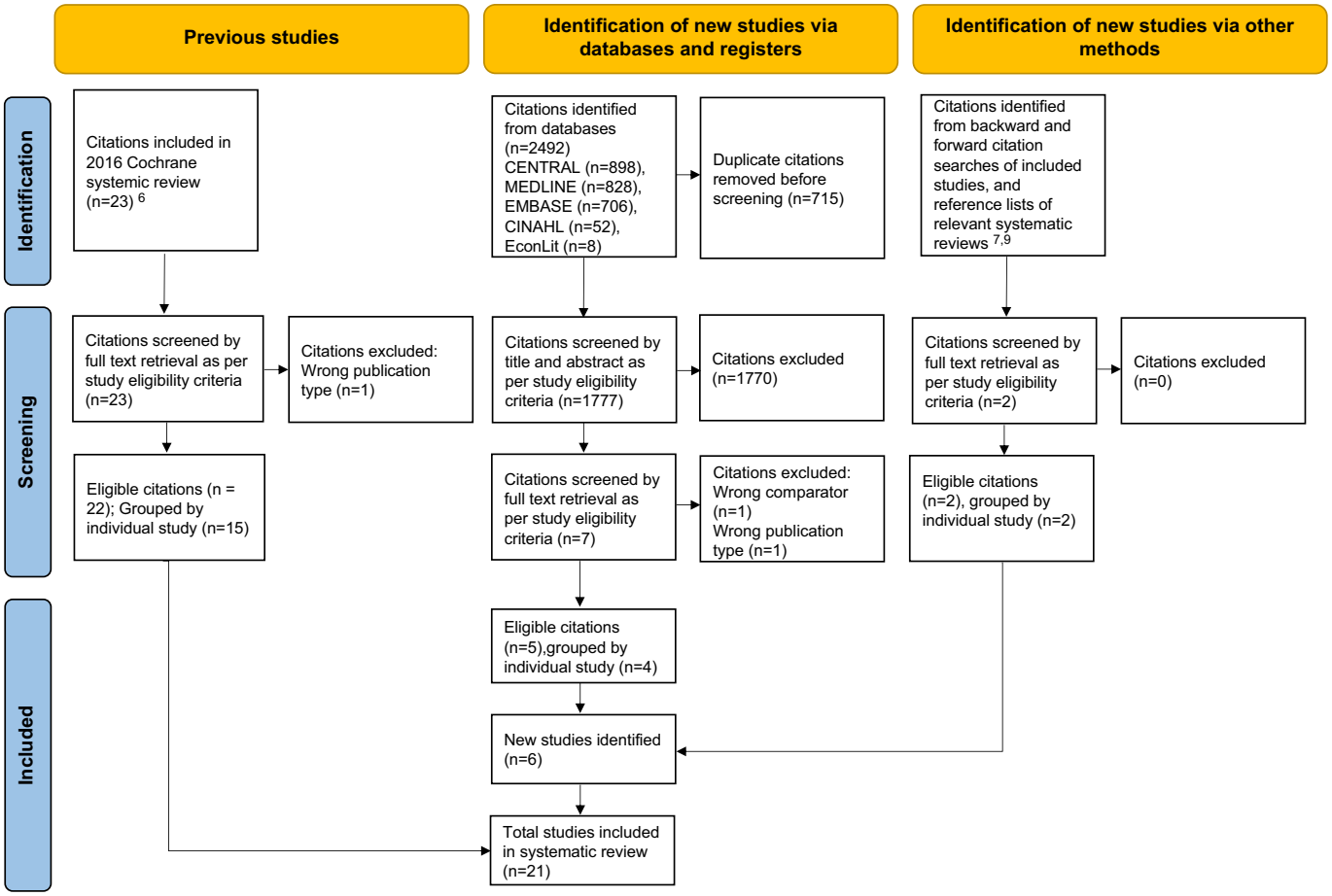

Fig. 1. PRISMA flowchart.

Mean differences (inverse-variance method) were calculated for continuous and risk ratios (Mantel-Haenszel method) for binary outcomes. Data are presented as forest plots with 95% CIs. Statistical significance of within-subgroup comparisons was considered at the $P < .05$ level (2-tailed). Heterogeneity was quantified by the τ^2 and I^2 statistics.

Reporting Bias and Certainty Assessments

A funnel plot for mortality (0-6 months) is presented as an assessment of reporting bias. Two reviewers (R.P., A.F.) assessed the certainty of evidence for outcomes using the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) approach.[39]

Results

Study Selection and Characteristics

We identified 21 eligible RCTs of HAH vs standard inpatient care (Table 1).[40-68] Fifteen studies were identified from a previous systematic review,[7] 4 from database and register searches, and 2 from other search methods (Figure 1). The total number of participants enrolled in all studies was 3459. The majority of studies (19) recruited small numbers of patients (fewer than 250), with the largest trial involving 1055 participants.[55] Three studies were excluded during full-text review, because of wrong publication type (conference abstracts without full text citation[69,70]) or comparison group (same HAH model comparing primary care vs specialist led[71]).

There is wide variability in the characteristics of recruited study populations. Three trials recruited participants of any age[44,47,48] [note Levine (2018)[50] and Levine (2019)[51] use the same protocol but recruited independent groups and are therefore considered separately] and 4 limited recruitment to older persons (1 specifically frail elderly patients with dementia)[40,55,57,67] with a variety of acute medical conditions requiring admission. Five trials recruited participants with an acute exacerbation of COPD,[42,43,45,50,53] 3 decompensated heart failure,[49,51,58] 2 acute ischemic stroke (clinically stable, requiring rehabilitation),[46,52] and 1 each for cellulitis,[41] community-acquired pneumonia,[54] febrile neutropenia post chemotherapy,[56] and respiratory tract infections in patients with neuromuscular disease.[59] A variety of workforce models were used in HAH. Overall clinical responsibility was held by either primary care physicians[40,41,54,67] or hospital specialists (respiratory,[42,43,45,50,59] geriatrics,[44,52,53,55,57,58] stroke,[46] general medicine,[47-49] cardiology,[51] or hematology-oncology[56]). Additional health care professionals included specialist nurses, district nurses, speech therapists, physiotherapists, occupational therapists, social workers, cultural link workers, psychologists, and pharmacists. Follow-up periods ranged from the end of the acute care episode to 12 months.

Risk of bias assessment identified some concerns in the majority of included studies, often relating to the measurement of outcome field (Table 2). The funnel plot for 6-monthly mortality is not clearly indicative of publication bias (Appendix 2).

Table 2
Risk of Bias Summary

	Randomization Process	Deviations From Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall
Caplan (1999)[40]	Low risk	Low risk	Low risk	Some concerns	Some concerns	Some concerns
Corwin (2005)[41]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Davies (2000)[42]	Some concerns	Low risk	Low risk	Some concerns	Low risk	Some concerns
Echevarria (2018)[43]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Harris (2005)[44]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Hernandez (2003)[45]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Kalra (2000)[46]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Levine (2018)[47]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Levine (2019)[48]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Mendoza (2009)[49]	Low risk	Low risk	Some concerns	Some concerns	Low risk	Some concerns
Nicholson (2001)[50]	Some concerns	Low risk	Low risk	Low risk	Low risk	Some concerns
Patel (2008)[51]	Low risk	Low risk	Some concerns	Low risk	Low risk	Some concerns
Ricauda (2004)[52]	Low risk	Low risk	Some concerns	Low risk	Low risk	Some concerns
Ricauda (2008)[53]	Low risk	Low risk	Some concerns	Low risk	Low risk	Some concerns
Richards (2005)[54]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Shepperd (2021)[55]	Low risk	Low risk	Some concerns	Some concerns	Low risk	Some concerns
Talcott (2011)[56]	Low risk	Low risk	Some concerns	Low risk	Low risk	Some concerns
Tibaldi (2004)[57]	Some concerns	Low risk	Low risk	Some concerns	Low risk	Some concerns
Tibaldi (2009)[58]	Low risk	Low risk	Low risk	Some concerns	Low risk	Some concerns
Vianello (2013)[59]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Wilson (1999)[60]	Low risk	Low risk	Some concerns	Some concerns	Low risk	Some concerns

Approach to Vital Sign Monitoring in Study Interventions

A brief description of the HAH intervention used in each study is provided in Table 1. In relation to the use of vital sign monitoring as a component of these interventions, the majority of studies[40-42,44,46,49,50,52-54,57,58,67] did not report sufficient information to specify the approach used. Of the remaining 8 studies, 2 main approaches to monitoring were identified—manual[43,45,51,55,56,59] and automated[47,48] (Figure 2). Compared with NICE guidance, no studies implemented remote monitoring technologies that met all recommended key standards.[34] A detailed description of vital sign monitoring in study interventions is provided in Table 3. Across all studies, the vital sign monitoring approach used in the control group is not described beyond referencing usual hospital care.

A manual approach to monitoring was characterized by the requirement for an individual in attendance with the patient (health care professional,[43,45,51,55] trained caregivers,[59] or the patient themselves[56]) to collect and record vital sign data using portable equipment temporarily placed on or attached to the patient. The frequency of data collection was either ad hoc at the discretion of health care professionals[45,55] and trained caregivers (in this study, a pulse oximeter was continuously attached but data collected intermittently)[59] or at predetermined regular intervals as specified in the intervention protocol.[43,51,56] Data relating to a variety of parameters were collected, including respiratory rate, peripheral oxygen saturation, heart rate, blood pressure, temperature, and weight. Two studies reported the means of data recording, both via written documentation on clinical forms.[43,51] Vital sign data were reviewed to guide changes in clinical management (including medication changes, readmission, or discharge decisions) based on a study protocol or following discussion by the visiting health care professional with their supervising physician.

Automated monitoring in the home treatment group was performed in 2 studies.[47,48] This approach was characterized by data relating to vital sign parameters (heart rate, respiratory rate, temperature) as well as additional data (accelerometry and falls) being collected and recorded continuously using wearable devices. In both studies, a small chest patch applied to the skin was used. Monitoring through machine-based algorithms subsequently produced alarms prompting clinical review. Further patient evaluation was available through remote (telephone, video, short message service) or home visits consultations with a physician. Reliability of the data coverage and feasibility of the approach used are not reported.

Effect of Interventions

The effects of interventions and individual study data comparing HAH to inpatient admission for each outcome were stratified by the approach to vital sign monitoring—automated, manual, and unspecified (Table 4). Exploratory stratified random effects meta-analyses pooled data on mortality (0-6 months), readmission (0-3 months), and length of stay were performed. The data were insufficient to carry out further analysis on the remaining outcomes.

Mortality (0-6 Months)

Mortality at 0-6 months' follow-up was analyzed using individual patient data from 12 studies (Figure 3). For HAH compared to hospital care, 6-monthly mortality risk ratio (RR) was 0.94 (95% CI 0.78-1.12, $P = .47$, 2552 participants, moderate certainty evidence). No statistically significant subgroup effect was observed (automated: RR 1.67, 95% CI 0.29-9.55, $P = .56$, 91 participants; manual: RR 0.93, 95% CI 0.71-1.21, $P = .58$, 1393 participants; unspecified: RR 0.93, 95% CI 0.73-1.19, $P = .59$, 1068 participants; $P = .80$, low certainty evidence).

Readmission to Hospital (0-3 Months)

Readmission to hospital at 0-3 months was analyzed using individual patient data from 10 studies (Figure 4). For HAH compared to hospital care, 3-monthly readmissions to hospital RR was 1.02 (95% CI 0.77-1.35, $P = .90$, 2170 participants, moderate certainty evidence). A statistically significant subgroup effect was observed (automated: RR 0.30, 95% CI 0.11-0.86, $P = .02$, 111 participants; manual: RR 1.02, 95% CI 0.71-1.47, $P = .93$, 1342 participants; unspecified: RR 1.23, 95% CI 0.84-1.79, $P = .29$, 717 participants; $P = .05$, low certainty evidence).

Length of Stay

Length of stay during the acute care episode was analyzed using individual patient data from 12 studies (Figure 5). For HAH compared with hospital care, the mean difference (MD) was 1.91 days (95% CI 0.71-3.12, $P = .002$, 2173 participants, low certainty evidence). No

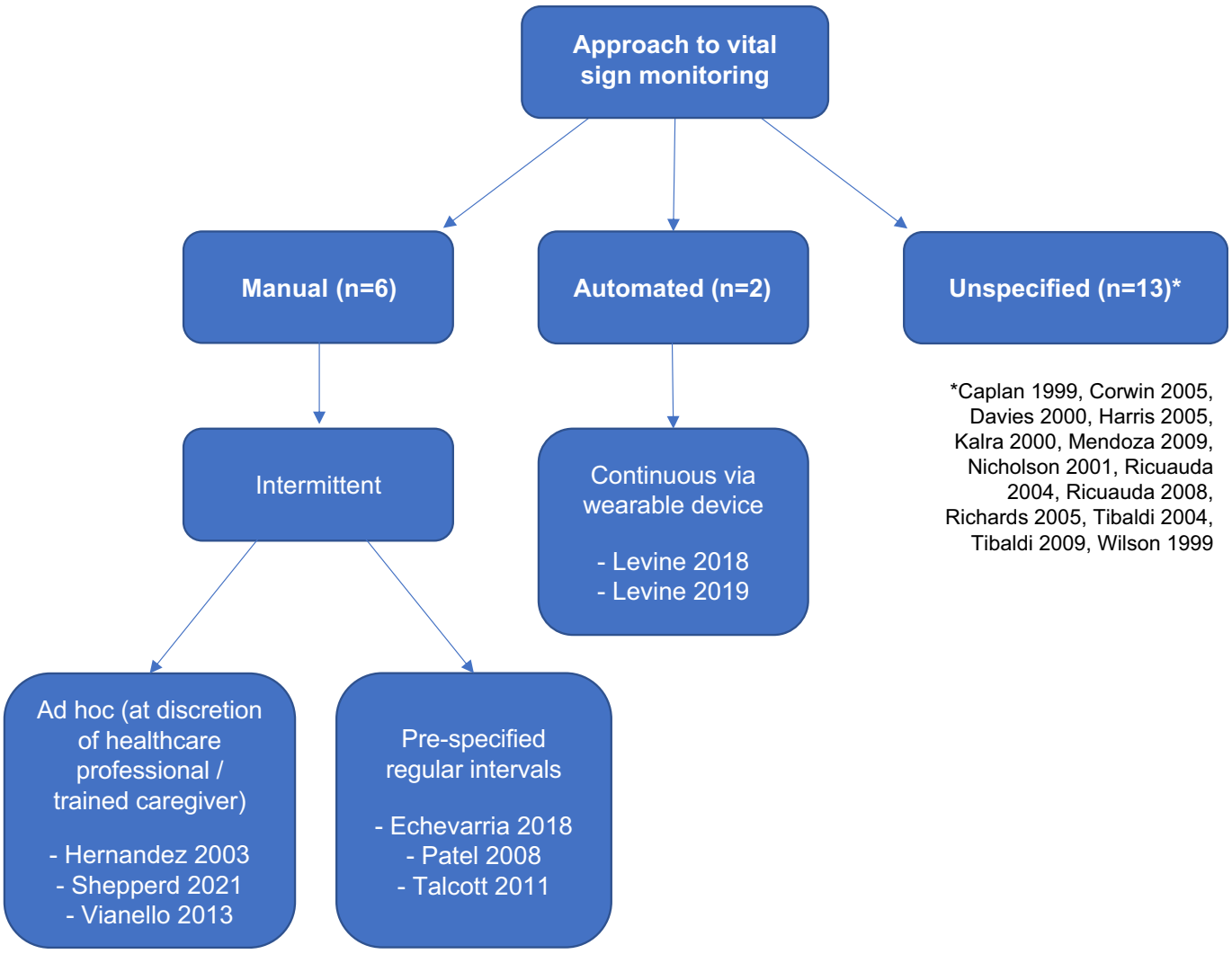

Fig. 2. Summary of vital sign monitoring approaches in HAH interventions.

statistically significant subgroup effect was observed (automated: MD 0.53, 95% CI −0.14 to 1.21, $P = .12$, 111 participants; manual: MD 0.97, 95% CI 0.06-1.88, $P = .04$, 1342 participants; unspecified: MD 4.07, 95% CI 0.48-7.67, $P = .03$, 720 participants; $P = .14$, very low certainty evidence).

Discussion

The principal findings of this review include the characterization of existing remote monitoring approaches and assessment of the technologies used in admission avoidance HAH. This has highlighted issues around insufficient reporting to determine the classification of monitoring approaches at home and to make a comparison with the way inpatient groups are monitored. Furthermore, this review suggests that the evaluation of continuous vital sign monitoring using wearable devices in HAH as an alternative to acute hospital stay is limited. The total number of participants involved in RCTs using this approach, 102 in total, is small when compared to the number of patients currently being remotely monitored in HAH services to avoid admission. The strengths of this review include a systematic and in-depth description of existing interventions and outcome measures that establishes the current evidence base to shape ongoing research and care delivery. The exploratory stratified analysis in this review corroborates existing reviews that justify the ongoing implementation of alternatives to inpatient admission for acute illness. It suggests that rates of safety outcomes are comparable to hospital admission (6-monthly mortality and 3-monthly readmission) and a potential association between automated monitoring and a reduction in readmission.

There are a number of limitations to this study. Study eligibility was limited to RCTs with inpatient admission as the control intervention. This was due to the absence of studies directly comparing approaches to vital sign monitoring in HAH and an intention to synthesize outcome data. Potential insights to be gained from cohort or case control studies of HAH interventions have therefore not been captured. The assessment of reporting bias is limited due the small number of eligible studies. The varied workforce models and heterogeneity of HAH interventions limits the insights that can be gained into the direct impact of the remote monitoring components on study outcomes. Furthermore, data pooling for the majority of outcomes was not feasible because of limited data availability. Outcomes with important safety and resource implications are reported by a minority of studies, including altered consciousness (evidenced by delirium or confusion rather than as a level on a score such as Glasgow Coma Scale) and utilization of investigations and treatments. Where data pooling was feasible, the imprecision, indirectness, and inconsistency

Table 3
Remote Vital Sign Monitoring in HAH Interventions

	Equipment and Devices Used (Local Regulatory Approval Status, Validated Accuracy of Oxygen Saturation Measurements in Black or Brown Skin)	Type of Data Collected	Procedures for Ensuring Optimal Data Acquisition	Method and Frequency of Data Collection	Arrangements for Data Transmission and Mitigating Loss of Data (Interoperability With Electronic Patient Records and Associated Devices)	Ways in Which the Data Is Displayed (Patient Interface With Easy-To-Use Design)	Process for Clinical Review (Risk Stratified Alerts, Trend-Based Alerts)	Technology Meets all "NICE 2023 Virtual Ward Platform Technologies Standards" (Standards in Parentheses Where Reported)
Caplan (1999)[40]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Corwin (2005)[41]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Davies (2000)[42]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Echevarria (2018)[43]	Pulse oximeter, automated blood pressure machine, manual blood pressure cuff and stethoscope, thermometer, timer, weighing scales (unknown, unknown)	Respiratory rate, peripheral oxygen saturation, heart rate, blood pressure, temperature and, if they have significant dependent edema, daily weight	Not reported	Manually performed by specialist respiratory nurses, once daily	Written documentation (no)	Clinical proforma (no)	Further discussion with respiratory consultant as required at the time of recording (no, no)	No
Harris (2005)[44]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Hernandez (2003)[45]	Pulse oximeter (Monitor PulsoxTM-3i; Minolta, AVL Medical Instruments AG, Osaka, Japan). Others not reported (yes, yes)	Peripheral oxygen saturation. Others not reported	Not reported	Manually performed by specialist respiratory nurses, intermittently at clinical discretion during home visit assessment	Not reported (no)	Not reported (no)	Escalation to hospital respiratory physician if needed following specialist respiratory nurse evaluation (no)	No
Kalra (2000)[46]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Levine (2018)[47]	Small skin patch (physIQ, Chicago, IL; VitalConnect, San Jose, CA) (yes, yes)	Heart rate, respiratory rate, telemetry, movement, falls, and sleep	Not reported	Automated via wearable device, continuous	Not reported (unknown)	Clinicians' smartphone software (unknown)	Monitoring was performed through machine-based algorithms, and clinical staff reviewed any alarms produced by these algorithms as part of their clinical care. Physician available for remote (telephone, video and short message service) and home visit consultations, including 24 h/d for urgent issues and visits. (yes, no)	No
Levine (2019)[48]	Small skin patch (VitalConnect), smartphones (yes, yes)	Temperature, heart rate, respiratory rate, telemetry, movement, and falls	Not reported	Automated via wearable device, continuous	Not reported (unknown)	Clinicians' smartphone software (unknown)	Monitoring was done through machine-based algorithms, which produced alarms for review by both nurse and physician. Physician available for remote (telephone, video and short message service) and home visit consultations,	No

							including 24 h/d for urgent issues and visits (yes, no)	
Mendoza (2009)[49]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Nicholson (2001)[50]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Patel (2008)[51]	Not reported (unknown, unknown)	Not reported	Not reported	Manually performed by specialist heart failure nurses, once daily or once every other day (as determined by the patient's health status)	Written documentation (no)	Case record form (no)	Drug adjustments were performed after specialist nurse assessment according to study protocol or after consultation with a cardiologist (no, no)	No
Ricauda (2004)[52]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Ricauda (2008)[53]	Pulse oximeter. Others not reported (unknown, unknown)	Peripheral oxygen saturation. Others not reported	Not reported	Not reported	Not reported (no)	Not reported (no)	Not reported (no, no)	No
Richards (2005)[54]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Shepperd (2021)[55]	Not reported (unknown, unknown)	Not reported	Not reported	Manually performed by nurse practitioners, intermittently at clinical discretion during home visit assessment	Not reported (no)	Not reported (no)	Weekday daily virtual ward round during which a plan of action, visits for the day, investigations required, and any adjustments to management plans were agreed. Attending geriatrician responsible for clinical review (no, no)	No
Talcott (2011)[56]	Automated blood pressure device, thermometer (unknown, unknown)	Blood pressure, temperature	Not reported	Manually performed by patients, 4 times daily	Not reported (no)	Not reported (no)	Patients examined daily by a home care nurse who used a written protocol and who was instructed to contact the primary physician if abnormal findings occurred (no, no)	No
Tibaldi (2004)[57]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA
Tibaldi (2009)[58]	Not reported (unknown, unknown)	Peripheral oxygen saturation, arterial blood pressure as needed. Others not reported	Not reported	Not reported	Not reported (no)	Not reported (no)	Not reported (no)	No
Vianello (2013)[59]	Pulse oximeter (9500; Nonin, Plymouth, MN) (yes, yes)	Peripheral oxygen saturation	Not reported	Manually performed by caregivers, intermittently at the discretion of trained caregivers	Not reported (no)	Not reported (no)	Caregivers instructed to use oximetry feedback as needed to return peripheral oxygen saturations to ≥95% by assisted coughing or NIV or both (no, no)	No
Wilson (1999)[60]	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported	NA

NA, not applicable.

Table 4
Summary of Findings

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
Mortality (0-6 mo)	12 (2552 participants)	Random effects meta-analysis	Overall: RR 0.94, 95% CI 0.78-1.12 ($P = .47$; 2552 participants) Automated: RR 1.67, 95% CI 0.29-9.55 ($P = .56$; 91 participants) Manual: RR 0.93, 95% CI 0.71-1.21 ($P = .58$; 1393 participants) Unspecified: RR 0.93, 95% CI 0.73-1.19 ($P = .59$; 1068 participants) No statistically significant subgroup effect ($P = .80$)	Overall effect: moderate certainty evidence ⊕⊕⊕o (downgraded because of imprecision) Subgroup effect: Low certainty evidence ⊕⊕oo (downgraded because of indirectness and imprecision)	Figure 3
Mortality (12 mo)	3	Data synthesis not performed, narrative summary of other data	Three studies reported mortality at 12 mo (2 using a manual approach to vital sign monitoring, and 1 unspecified), with no significant differences found between intervention and control. These data were not included in the meta-analysis to limit the range of follow-up intervals, and because of the reduced direct effect of the intervention and influence of confounding variables on mortality rates at this prolonged interval.	NA	Manual: Patel (2008)[51]: intervention (I) = 2/13, control (C) = 2/18 Shepperd (2021)[55]: I = 188/700, C = 82/355, ARR 1.14 (95% CI 0.80-1.62, $P = .47$) Unspecified: Mendoza (2009)[49]: I = 2/37, C = 3/34
Transfer to hospital (during acute care episode)	10	Data synthesis not performed, narrative summary of other data	The rate of transfer to hospital during the acute care episode is reported in 10 studies (3 using a manual approach to vital sign monitoring, and 7 unspecified). The data were insufficient to carry out further analysis. A wide range in transfer to hospital rates regardless of approach used is noted, likely reflecting the heterogeneity in the populations and interventions between studies.	NA	Manual: Shepperd (2021)[55]: I = 37/700, C = NA Talcott (2011)[56]: I = 4/47, C = NA Vianello (2013)[59]: I = 8/26, C = NA Unspecified: Caplan (1999)[40]: I = 4/51, C = NA Davies (2000)[42]: I = 9/100, C = NA Kalra (2000)[46] : I = 51/149, C = NA Mendoza (2009)[49]: I = 0/37, C = NA Ricauda (2008)[53]: I = 5/52, C = NA Richards (2005)[54]: transfer to hospital plus readmission within 2 wk of discharge: I = 2/24, C = 1/25 Tibaldi (2009)[58]: I = 4/48, C = NA
Readmission to hospital (0-3 mo)	10 (2170 participants)	Random effects meta-analysis	Overall: RR 1.02, 95% CI 0.77-1.35 ($P = .90$; 2170 participants) Automated: RR 0.30, 95% CI 0.11-0.86 ($P = .02$; 111 participants) Manual: RR 1.02, 95% CI 0.71-1.47 ($P = .93$; 1342 participants) Unspecified: RR 1.23, 95% CI 0.84-1.79 ($P = .29$; 717 participants) Statistically significant subgroup effect ($P = .05$)	Overall effect: moderate certainty evidence ⊕⊕⊕o (downgraded because of imprecision) Subgroup effect: Low certainty evidence ⊕⊕oo (downgraded because of indirectness and imprecision)	Figure 4
Readmission to hospital (3-12 mo)	4	Data synthesis not performed, narrative comparison of other data	4 studies reported readmission rates at 3-12 mo (all with an unspecified approach to vital sign monitoring), with 1 study	NA	Unspecified: Caplan (1999)[40]: readmission at 6 mo: I = 7/51, C = 5/49, RR 1.35 (0.46-3.96)

			identifying a significantly reduced readmission rate at 6 mo compared with controls. These data were not included in the meta-analysis to limit the range of follow-up intervals, and because of the reduced direct effect of the intervention and influence of confounding variables on readmission rates at this prolonged interval.		Mendoza (2009)[49]: readmission for heart failure at 12 mo: I = 15/37, C = 17/34 Ricauda (2008)[53]: readmission at 6 mo: I = 17/41, C = 34/39 (*P* = .001) Tibaldi (2009)[58]: readmission at 6 mo: I = 8/47, C = 18/53 (*P* = .19)
Clinical complications	9	Data synthesis not performed, narrative summary of other data	Clinical complications during the acute care episode are reported in 9 studies (2 using an automated approach to vital sign monitoring, 2 manual, and 5 unspecified). This is variably measured across studies, with 20 types of adverse event(s) reported. Five studies report the number of total clinical complications (no standardized definition). Data were insufficient to carry out further analysis.	n/a	Automated: Levine (2018)[47]: adverse events (n): I = 0, C = 2. Inappropriate medication use: I = 0, C = 1. Foley use: I = 0, C = 0. Restraint use: I = 0, C = 0. Levine (2019)[48]: any safety event: I = 4/43, C = 7/47. Inappropriate medication use (n): I = 0, C = 5. Foley use: I = 0, C = 2. Restraint use: I = 0, C = 0. Manual: Shepperd (2021)[55]: delirium at 1 mo: I = 10/588, C = 13/295 (ARR 0.38 95% CI 0.19-0.76; *P* = .006). Comorbidities at 6 mo (mean difference) = 0.0002, 95% CI −0.015 to 0.15 (*P* = .998). Talcott (2011)[56]: any major medical complication: I = 4/44, C = 5/63 (*P* = .56) Unspecified: Caplan (1999)[40]: total clinical complications: I = 11.8%, C = 16.3% (ns). Confusion: I = 0/50, C = 10/49 (*P* = .0005). Falls: I = 1/50, C = 2/49 (ns). All bowel complications: I = 0/50, C = 11/49 (*P* = .0003). Constipation: I = 0/50, C = 7/49 (*P* = .13). Fecal incontinence: I = 0/50, C = 4/49 (ns). All urinary complications: I = 1/50, C = 8/49 (*P* = .01). Urinary incontinence: I = 1/50, C = 6/49 (ns). Urinary retention: I = 0/50, C = 2/49 (ns). Phlebitis: I = 2/50, C = 3/49 (ns). Pressure area/skin tear: I = 1/50, C = 3/49 (ns). Ricauda (2004)[52]: Respiratory infections: I = 16/60, C = 20/66 (ns). Urinary infections: I = 12/60, C = 15/66 (ns) Ricauda (2008)[53]: Medical complications: did not differ. Urinary tract infections: I = 1%, C = 6% (*P* = .049) Richards (2005)[54]: Extrapulmonary infections (n): I = 5, C = 4.

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					Pulmonary complications: I = 2, C = 1. Falls: I = 0, C = 1. Tibaldi (2004)[57]: Sleeping disorders: I = 5/56, C = 23/53 (MD: −34%, 95% CI −50% to −19%; $P < .001$). Agitation/aggressiveness: I = 5/56, C = 22/53 (MD: 33%, 95% CI −48% to −17%; $P < .001$). Feeding disorders: I = 5/56, C = 21/53 (MD: 31%, 95% CI −46% to −16%; $P < .001$)
Treatment efficacy	5	Data synthesis not performed, narrative comparison of other data	The efficacy of treatment provided during the acute care episode are reported in 5 studies (2 using a manual approach to vital sign monitoring, 3 unspecified). This is variably measured across studies, with outcomes including duration of symptoms, duration of therapeutic management, time to recovery, improvement in pain, treatment failure, and change in disease-specific severity index. Data were insufficient to carry out further analysis.	NA	Manual: Talcott (2011)[56]: duration of fever, median (range): I = 3 (1-14), C = 3 (0-13) ($P = .94$). Duration of neutropenia: I = 4 (1-15), C = 4 (1-10) ($P = .80$). Duration of fever and neutropenia: I = 4 (1-15), C = 4 (2-13) ($P = .70$). Reported pain decrease: I = −13.1, C = 2.72 ($P = .01$) Vianello (2013)[59]: treatment failure: I = 8/26, C = 13/27 ($P = .19$), time to recovery, d, mean (SD): I = 8.9 (4.6), C = 9 (8.9) ($P = .21$) Unspecified: Corwin (2005)[41]: days to no advancement of cellulitis, mean (SD): I = 1.5 (0.11), C = 1.49 (0.1) (MD 0.01, 95% CI −0.3 to 0.28). Days to no advancement of cellulitis (comparison with covariates), HR (95% CI) (HR >1 implies home care treatment was faster; HR <1 implies home care treatment took longer): 0.98 (0.74-1.34); $P = .97$. Days on intravenous antibiotics: 0.84 (0.63-1.12); $P = .23$. Days to discharge: 0.95 (0.71-1.26); $P = .71$. Days on oral antibiotics: 1.18 (0.88-1.59); $P = .27$. SF-36 Pain, day 6 (MD): −3.8, 95% CI −10.6 to 3.0 (ns) Davies (2000)[42]: change in postbronchodilator FEV_1 (liters) at 3 mo, mean (SD): I = 0.11 (0.34), C = 0.14 (0.32) (ns) Richards (2005)[54]: median duration of intravenous antibiotics (days): I = 3, C = 2 ($P = .22$), median duration of oral antibiotics, d: I = 9, C = 7 ($P = .22$)

Functional status and physical activity	12	Data synthesis not performed, narrative summary of other data	Physical and functional status are reported in 12 studies (2 using an automated approach to vital sign monitoring, 2 manual and 8 unspecified). All of these studies use a scale or index to measure the extent to which participants function independently in their activities of daily living, with or without a comparison to baseline. There are 8 different measurement tools used across studies. 2 studies also report place of residence at discharge from the acute care episode or at follow-up, as a measure of the subsequent impact of decline in functional status. Measurement of participants' physical activity during the acute care episode was reported in both studies using automated vital sign monitoring. Data were insufficient to carry out further analysis, however it illustrates a further benefit of continuous monitoring using wearable devices in allowing additional outcomes (such as levels of physical activity, sleep patterns, fall detection) to be feasibly and accurately measured.	NA	Automated: Levine (2018)[47]: physical activity, min, median (IQR): I = 209 (90), C = 78 (44) ($P < .01$). Sleep, h: I = 5.4 (1.9), C = 4.1 (3.0) ($P = .33$). Steps: I = 1820 (3300), C = 159 (508) ($P = .06$). Upright posture, h: I = 4.8 (1.4), C = 2.7 (1.8) ($P < .01$). ADL (activities of daily living), worse at discharge: I = 0/10, C = 1/11. IADL (instrumental activities of daily living) worse at discharge: I = 0/10, C = 2/11 Levine (2019)[48]: % day sedentary, median (IQR): I = 12 (15), C = 23 (23). % day lying down: I = 18 (32), C = 55 (66). IADL worse at 30 d: I = 14/38, C = 13/38. ADL worse at 30 d: I = 4/38, C = 6/38 Manual: Shepperd (2021)[55]: Barthel index: I = 521, C = 256 (MD 0.24, 95% CI 0.33-0.80; $P = .40$). Living at home, 6 mo: I = 528/672, C = 247/328 (ARR 1.05, 95% CI 0.95-1.15; $P = .36$). Living at home, 12 mo: I = 443/670, C = 219/325 (ARR 0.99, 95% CI 0.89-1.10; $P = .8$) Talcott (2011)[56]: Change in role function EORTC QLQ C-30 subscale: I = 0.58, C = 0.78 ($P = .05$) Unspecified: Caplan (1999)[40]: Barthel score, admission to discharge (mean, SEM): I = 0.37 (0.27), C = −0.04 (0.27) (ns). IADLs, admission to discharge: I = 0.65 (0.23), C = −0.08 (0.26) ($P = .37$) Corwin (2005)[41]: SF-36 Physical functioning, mean difference at day 6: −5.2 95% CI -13.7, 3.2 (ns). SF-36 Role physical: 2.2 95% CI -10.7, 15.1 (ns) Kalra (2000)[46]: independent on Rankin scale, 3 mo: I = 107/145, C = 125/152 (RR 1.12, 95% CI 0.99-1.26; $P = .06$). Modified Rankin, 12 mo, median (IQR): I = 2 (1-4), C = 2 (1-3) ($P = .14$). Barthel 0-20 (higher score = greater independence). Barthel score 15-20, 3 mo: I = 106/145, C = 123/152 (RR 1.11, 95% CI 0.99−1.25; $P = .09$). Bathel score 15-20, 12 mo: I = 102/144, C = 131/152 (RR 1.22 95%CI 1.09−1.37; $P = .001$)

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					Mendoza (2009)[49]: Initial Barthel, mean (SD): I = 86.4 (12.5), C = 80.5 (16.6), 12-mo Barthel: I = 90.4 (11.9) (P = .103), C = 84.5 (15.5) (P = .248). Variation in Barthel index: I = 4.0 (−0.9-8.9; P = .21), C = 4.7 (−2.2-11.5; P = .21) Ricauda (2004)[52]: ADL score, median (IQR): I = 4 (2−5), C = 4 (2−6) (P = .57). Functional Impairment Measure score, mean (IQR): I = 106.0 (67.5−121.5), C = 96.5 (56.5−116.5) (P = .26). Canadian Neurological Scale score, mean (IQR): I = 10.0 (8.5-10.0), C = 9.5 (7.0-10.0) (P = .39). National Institutes of Health Stroke Scale score: I = 8 (4-26), C = 8 (6-24) (P = .37). Discharge destination home: I = 43/44, C = 21/46 Ricauda (2008)[53]: Change in ADL score, mean (SD): - I = 0.12 (0.64), C = 0.08 (0.73) (P = .81). Change in IADL score: I = −1.4 (2.6), C = −0.6 (1.9) (P = .10). Tibaldi (2009)[58]: Barthel Index (mean difference, SD): I = −1.95 (9.61), C = −0.30 (10.12) (P = .40). IADLs: I = −0.95 (1.97), C = −0.54 (1.92) (P = .29). Wilson (1999)[60]: Barthel Index at 3 mo [median (IQR)]: I = 16 (13-19), C = 16 (12-20)
Mental health and cognitive status	8	Data synthesis not performed, narrative summary of other data	Physical and functional status are reported in 8 studies (3 using a manual approach to vital sign monitoring and 5 unspecified). 7 studies use mental health measures (anxiety, emotional function and Philadelphia geriatric morale scale in 1 study each, geriatric depression scale in 4 studies). 4 studies provide a measure of cognitive function, with or without a comparison to baseline. 3 different measurement tools were used across these studies. Data were insufficient to carry out further analysis.	NA	Manual: Echevarria (2018)[43]: Change in HADS-A, 90 d, median (IQR): I = 0 (−2 to 3), C = 0 (−3 to 2). Change in HADS-D, 90 d: I = −0.5 (−3 to 1.25), C = 0 (−2 to 3). Shepperd (2021)[55]: Cognitive impairment at 6 mo: I = 406, C = 183 (RR 1.06, 95% CI 0.93-1.21; P = .36) Talcott (2011)[56]: Emotional Function scores: I = 3.27, C = −6.94 (P = .04) Unspecified: Caplan (1999)[40]: Mental Status Questionnaire score, admission to discharge, mean (SD): I = 0.43 (0.12), C = 0.27 (0.12) (ns) Ricauda (2004)[52]: Geriatric Depression Scale score: I = 10 (5-15), C = 17 (13-20) (P < .001)

Health-related quality of life	10	Data synthesis not performed, narrative summary of other data	Health-related quality of life is reported in 10 studies (3 using a manual approach to vital sign monitoring and 7 unspecified). There are 8 general and 2 disease-specific measurement indices used to measure this outcome across studies. Data were insufficient to carry out further analysis.	NA

Ricauda (2008)[53]: Change in Geriatric Depression Scale score, mean (SD): I = −3.1 (4.7), C = 0.7 (3.2) (*P* = .00). Change in Mini-Mental State Examination score: I = −0.4 (4.0), C = −0.5 (1.8) (*P* = .88)

Tibaldi (2009)[58]: Geriatric Depression Scale, MD (SD): I = 1.48 (1.86), C = 0.12 (3.36) (*P* = .02). Mini-Mental State Examination: I = 0.07 (1.38), C = 0.08 (1.36) (*P* = .97)

Wilson (1999)[60]: Philadelphia Geriatric Morale Scale, 3 mo, median (IQR): I = 37 (30-42), C = 37 (31-43) (MD 0, 95% CI −4.1 to 4.1)

Manual:

Echevarria (2018)[43]: Utility (EQ-5D-5 L) score, 90 d, mean (SD): I = 0.003 (0.287), C = 0.007 (0.338). Change in CAT, 90 d: I = −3.0 (−8 to 1), C = −1.0 (−6 to 1)

Hernandez (2003)[45]: Mean change in St George's Respiratory Questionnaire (SGRQ) score: I = −6.9, C = −2.4 (*P* = .05). Mean change SF-12 (physical) score: I = 1.7, C = 1.9 (ns)

Shepperd (2021)[55]: Quality of life at 6 mo: 0.32, 95% CI −3.08 to 3.73. Quality-adjusted life years from baseline to 6 mo (adjusted): I = 0.245, C = 0.247 (MD −0.002, 95% CI −0.013, 0.010)

Unspecified:

Davies (2000)[42]: Change in SGRQ, 3 mo, mean (SD): I = −0.48 (16.92), C = −3.13 (14.02) (ns)

Kalra (2000)[46]: QALY gained, mean (SD): I = 0.221 (0.344), C = 0.297 (0.257)

Mendoza (2009)[49]: Idem in SF-36 physical component: I = 3.6 (−0.5 to 7.7; *P* = .47), C = 2.2 (−1.9 to 6.4; *P* = .47). Idem in SF-36 mental component: I = 4.0 (−0.9 to 8.9; *P* = .38), C = 2.8 (−2.4 to 8.0; *P* = .38). MLHFQ 12 mo (mean difference): 5.7, 95% CI −3.7 to 15.1 (*P* = .229). SF-36 physical health summary score: −1.8, 95% CI 6.7-3.1 (*P* = .467). SF-36 mental health summary score: −2.2, 95% CI −7.3 to 2.8 (*P* = .381). Initial EQ-5D, mean (SD): I = 48.4 (12.8), C = 48.9 (18.2). 12-mo EQ-5D: I = 55.8 (15.3) (*P* = .036), C = 53.5 (16.8) (*P* = .218)

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					Ricauda (2008)[53]: Change in Nottingham Health Profile score, mean (SD): I = 3.6 (7.9), C = 0.8 (4.5) (P = .04) Richards (2005)[54]: Mean SF-12 physical, 6 wk: I = 42.2, C = 45.8 (P = .18). Mean SF-12 mental, 6 wk: I = 50.4, C = 51.0 (P = .81) Tibaldi (2009)[58]: Nottingham Health Profile, mean (SD): I = 1.09 (2.57), C = 0.18 (1.94) (P = .046) Wilson (1999)[60]: Sickness Impact Profile, 3 mo, median (IQR): I = 24 (20-31), C = 26 (20-31) (MD −2, 95% CI −4 to 4, P = .73). EuroQol at 3 mo (median): I = 0.64, C = 0.63 (MD 0.01, 95% CI −0.12 to 0.09; P = .94)
Length of stay	12 (2173 participants)	Random effects meta-analysis	Overall: MD 1.91, 95% CI 0.71-3.12 (P = .002; 2173 participants) Automated: MD 0.53, 95% CI −0.14 to 1.21 (P = .12; 111 participants) Manual: MD 0.97, 95% CI 0.06-1.88 (P = .04; 1342 participants) Unspecified: MD 4.07, 95% CI 0.48-7.67; (P = .03; 720 participants) No statistically significant subgroup effect (P = .14)	Overall effect - low certainty evidence ⊕⊕oo (downgraded because of imprecision and inconsistency) Subgroup effect: very low certainty evidence ⊕⊕oo (downgraded because of indirectness, imprecision and inconsistency)	Figure 5
Use of medication	6	Data synthesis not performed, narrative summary of other data	The use of medication during the acute care episode is reported in 6 studies (2 using an automated approach to vital sign monitoring, 1 manual and 3 unspecified). This is variably measured across studies, with outcomes reported including intravenous medications, change in antibiotic, proportion prescribed an antibiotic at follow-up, disease-specific treatments (for COPD) and antipsychotic medication (for the management of agitation). Data were insufficient to carry out further analysis.	NA	Automated: Levine (2018)[47]: use of intravenous medication: I = 6/9, C = 9/11 (P = .62) Levine (2019)[48]: use of intravenous medication: I = 30/43, C = 39/48 Manual: Talcott (2011)[56]: antibiotics changed after random assignment: I = 4/44, C = 16/66 (P = .04) Unspecified: Davies (2000)[42]: proportion of patients prescribed an antibiotic at 3 mo: I = 56/100, C = 19/50 (MD 18%, 95% CI 1.4%-34.6%) Ricauda (2008)[53]: Use of oxygen therapy: I: 30/52, C = 38/52 (P = .55). Use of intravenous antibiotics: I: 40/52, C = 39/52 (P = .95). Use of intravenous steroids: I: 23/52, C = 27/52 (P = .77). Use of beta-agonist bronchodilators: I: 20/52, C = 25/52 (P = .66). Use of anticholinergic bronchodilators: I: 26/52, C = 21/52 (P = .67)

					Tibaldi (2004)[57]: use of antipsychotic drugs on admission: I = 26/56, C = 18/56 (MD 14.3%, 95% CI −3.7% to 31.1%). Use of antipsychotic drugs on discharge: I = 6/56, C = 13/53 (MD 14%, 95% CI −28% to 0.3%)
Use of investigations	4	Data synthesis not performed, narrative summary of other data	The use of medication during the acute care episode is reported in 4 studies (2 using an automated approach to vital sign monitoring and 2 unspecified). This is variably measured across studies, with outcomes reported including use of imaging, laboratory orders, electrocardiography, echocardiography, and visits to hospital for diagnostic procedures. Data were insufficient to carry out further analysis.	NA	Automated: Levine (2018)[47]: use of imaging: I = 1/9, C = 5/11 ($P = .16$). Use of laboratory orders (IQR): I = 6 (6), C = 19 (22) ($P < .01$) Levine (2019)[48]: use of imaging: I = 6/43, C = 21/48. Use of laboratory orders (IQR): I = 3 (5), C = 15 (15) Unspecified: Mendoza (2009)[49]: use of electrocardiography: I = 1.3 (0.6), C = 3.4 (2) ($P = .001$). Use of echocardiography: I = 0.4 (0.5), C = 0.9 (0.4) ($P = .001$). Use of thorax radiography: I = 1.2 (0.7), C = 2 (0.6) ($P = .001$). Use of laboratory tests: I = 3.5 (1.5), C = 4.9 (1.9) ($P = .001$). Ricauda (2008)[53]: visits to hospital for diagnostic procedures: I = 11/52, C = NA
Health care professional interactions (during acute care episode)	7	Data synthesis not performed, narrative summary of other data	Interactions between health care professionals and participants during the acute care episode are reported in 7 studies (2 using an automated approach to vital sign monitoring, 1 manual and 4 unspecified). This is variably measured across studies, with outcomes reported including the number of home physician and nurse visits, consultation sessions, total physician time consumed, and duration of allied health care professional therapy (latter in single study involving stroke patients). Data were insufficient to carry out further analysis.	NA	Automated: Levine (2018)[47] consultant session: I = 0/10, C = 5/11. PT/OT session: I = 1/9, C = 3/11. Physician visits, median (range): I = 1 (1-3), C = NA. Nurse visits: I = 0/10, C = NA. Levine (2019)[48] consultant session: I = 1/43, C = 15/48. PT/OT session: I = 0/43, C = 8/47 Manual: Patel (2008)[51]: number of home visits, median (IQR): I = 4 (3.5-4.5), C = NA. Total physician time consumed, h, median (IQR): I = 0.53 (0.3-1.1), C = not reported. Unspecified: Davies (2000)[42]: number of home visits, mean (SD): I = 11 (3), C = NA Kalra (2000)[46]: physiotherapy duration per patient, h, median (IQR): I = 7.3 (3.0−13.8), C = 21.5 (12·0−39.3). Occupational therapy duration per patient, h, median (IQR): I = 3.0 (2.0-6.0), C = 6.0 (3.0-11.5). Speech therapy duration per patient, h, median (IQR): I = 2.0 (1.2-4.3), C = 4.2 (2.2-8.4) Ricauda (2008)[53]: nursing visits, median (range): I = 11 (3-38), C =

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					NA. Physician visits, median (range): I = 8 (2-28), C = NA. Tibaldi (2009)[58]: number of nurse visits, mean (SD): I = 13.8 (9), C = NA. Number of physician visits: I = 11.1 (6.2), C = NA
Contact with health care services (following acute care episode)	5	Data synthesis not performed, narrative summary of other data	Contact with health care services following the acute care episode is reported in 5 studies (2 using an automated approach to vital sign monitoring and 3 manual). This is variably measured across studies with respect to follow-up interval and services access (primary care, emergency department, and secondary care specialist clinics). Data were insufficient to carry out further analysis.	NA	Automated: Levine (2018)[47]: primary care visit at 14 d: I = 7/9, C = 4/11 (P = .09). Emergency department presentation at 30 d: I = 1/9, C = 2/11 (P = 1) Levine (2019)[48]: primary care visit at 14 d: I = 22/40, C = 19/45. Emergency department presentation at 30 d: I = 3/43, C = 11/48 Manual: Echevarria (2018)[43]: accident and emergency attendances at 90 d: I = 29/60, C = 26/58. General practice appointments at 90 d: I = 26/60, C = 30/58. Secondary care appointments at 90 d: I = 48/60, C = 41/58 Hernandez (2003)[45]: emergency department attendances at 8 wk, mean (SD): I = 11 (9.6), C = 21 (22.3) (P = .02) Patel (2008)[51]: number of visits to heart failure clinic at 12 mo, mean (SD): I = 7.2 (10), C = 3.6 (5.2) (not statistically significant, ns)
Social care requirements (following acute care episode)	6	Data synthesis not performed, narrative summary of other data	Social care requirements following the acute care episode is reported in 6 studies (2 using a manual approach to vital sign monitoring and 4 manual). This is variably measured across studies with outcomes reported including referral for social support or social care package at discharge, living in long-term residential care at follow-up and total hours of care received. Data were insufficient to carry out further analysis.	NA	Manual: Echevarria (2018)[43]: social care package post discharge: I = 7/60, C = 5/58 Shepperd (2021)[55]: Long-term residential care, 6 mo: I = 37/649, C = 27/310 (ARR 0.58, 95% CI 0.45-0.76; P < .001). Long-term residential care, 12 mo: I = 39/649, C = 27/310 (ARR 0.61, 95% CI 0.46-0.82; P < .001) Unspecified: Davies (2000)[42]: referred for social support: I = 24/100, C = 3/50 (difference 18%, 95% CI 7.3%-28.6%) Kalra (2000)[46]: Institutionalization, 3 mo: I = 15/146 C = 9/152 (P = .17). Institutionalization, 6 mo: I = 15/144, C = 9/152 (P = .16). Institutionalization, 12 mo: I = 13/144, C = 8/152 (P = .21). Received informal care: I = 100/

Cost	16	Data synthesis not performed, narrative summary of other data	Costs were reported in 16 studies (2 using an automated approach to vital sign monitoring, 6 manual and 8 unspecified). Across studies, costs are reported for the acute care episode, acute care episode plus period of follow-up, with or without social or informal care costs. Only 4 studies included a full economic evaluation. Data synthesis was not considered feasible because of the variety of means by which costs were calculated. A systematic health economic evaluation of HAH compared to inpatient care was not undertaken as it was considered to be outside the scope of this review. The cost of monitoring equipment is reported to have been included in the total cost calculations in both the studies using automated vital sign monitoring (cost breakdown data not provided) and not included or reported in the 6 studies using a manual approach. Data were insufficient to carry out further analysis.	NA

140, C = 94/148. Total hours of care over 12 mo (SD): I = 979 (1749), C = 1435.63 (2278)
Ricauda (2004)[52]: Admitted to nursing home, 6 mo: I = 3/60, C = 16/60 ($P = .0003$)
Ricauda (2008)[53]: Transfer to long-term facilities at end of acute episode: I = 0/52, C = 6/52
Automated:
Levine (2018)[47]: Mean direct cost, acute care episode, mean percentage difference (IQR): I = 52% (28%) lower ($P = .05$). Mean direct cost, acute care episode +30-d discharge: I = 67% (77%) lower ($P < .01$)
Levine (2019)[48]: Relative adjusted mean cost reduction with physician labor, acute care episode (95% CI): I = 19% (4-31) lower ($P = .017$). Relative adjusted mean cost reduction with physician labor, acute care episode + 30-d discharge (95% CI): I = 25% (10-38) lower ($P < .001$)
Manual:
Echevarria (2018)[43]: health and formal social care cost, 90 d, mean (SD): I = 3857.8 (3199.6), C = 4873.5 (5631.1)
Hernandez (2003)[45]: average cost per patient (95% CI): I = €1255.12 (978.54-1568.04), C = €2033.51 (1547.05-2556.81) ($P = .003$)
Patel (2008)[51]: Total initial cost, median (IQR): I = €586 (334-1125), C = €3277 (2125-5750) ($P < .001$)
Shepperd (2021)[55]: Adjusted total health and social care costs: I = €15,124, C = €17,390 (MD −2265, SE 1027, 95% CI 4279 to −252). Adjusted total societal costs: I = €19,067, C = €21,907 (MD −2840, SE 1354, 95% CI −5495 to 185)
Talcott (2011)[56]: Total direct cost estimate, charges, mean (SD): I = $10,977 (5686), C = $16,341 (7652) ($P < .01$). Total direct cost estimate, cost estimate: I = $7830 (3786), C = $10,143 (4678) ($P < .01$)
Vianello (2013)[59]: Total cost of patient care, mean (SD): I = €542 (258.5), C = €8890 (10,992.7) ($P < .001$). Daily cost of patient care,

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					mean (SD): I = €65.3 (18.6), C = €1060 (592.5) ($P < .001$) Unspecified: Caplan (1999)[40]: cost per day (95% CI): I = $191 (175-208), C = $484 (465.10-503.54) *Cost data financial year 1995/1996. Cost per episode: I = $1764 (1416-2111), C = $3614 (2881-4347) ($P < .001$) Kalra (2000)[46]: Total care costs excluding informal care, mean (SD): I = £6840 (9353), C = £11,450 (9745). Total care costs including informal care costs based on home help rate, mean (SD), I = £17,226 (21,442), C = £26,738 (26,817) ($P = .001$). Additional cost per additional QALY gained excluding informal care: I = NA, C = £64,097. Additional cost per additional QALY gained based on home help rate: I = NA, C = £136,609 Mendoza (2009)[49]: Cost of index stay, , mean (SD): I = €1991 (1159), C = €3771 (1912) ($P < .001$). Total cost per index episode, mean (SD): I = €2541 (1334), C = €4502 (2153) ($P < .001$). Total cost during follow-up per patient, mean (SD): I = €3425 (4948), C = €4619 (7679 ($P = .83$) *Costs include health service costs used during follow-up period of 1 y, excludes informal care. Nicholson (2001)[50]: Cost per episode, mean (95% CI): I = $745 (595-895), C = $2543 (1766-3321) ($P < .01$). Cost effectiveness per patient episode ratio: 3:1 (favors intervention). *T + C costs: GP 10% of costs, domiciliary allied health 21% of costs, community nursing 28% of costs (= 59% of costs) and hospital care 41% of costs. If C = $895, then T = $1287 (59% of costs). Total costs = $2182 per patient episode of care. Costs based on financial year 99/00; Used average DRG costs (Australian dollars), patient data for ED costs, and modeled costs for OPD clinic visits. HAH care individual costs, included direct and indirect costs. GP costs at $91.00 per hour.

Patient satisfaction	9	Data synthesis not performed, narrative summary of other data	Patient experience of the care they received is reported in 9 studies (2 using an automated approach to vital sign monitoring, 2 manual, and 5 unspecified). This is variably measured across studies, with outcomes reported relating to satisfaction with transitions of care and overall care (with or without using questionnaire scales), whether they would recommend the care they received and preference for location of care. Data were insufficient to carry out further analysis.	NA	Ricauda (2008)[53]: Total mean cost: I = $1175.90, C = $1390.9 ($P$ = .38). Cost per patient per day, mean (SD): I = $101.4 (61.3), C = $151.7 (96.4) ($P$ = .002) Richards (2005)[54]: Mean cost per patient, NZ$: I = 1157.90, C = 1556.28 Tibaldi (2009)[58]: Mean total cost: I = €1820.92, C = €2116.89 (P < .001). Cost per patient per day: I = €110.98, C = €280.62 Wilson (1999)[60]: Cost of initial episode (95% CI): I = £2568.9 (2089.3-2972.1), C = £2880.6 (2316.1-3547.8) (MD −311.7, P > .43) *Bootstrap difference using 1000 subsamples: −304.72 (−1112.4 to 447.9). Mean cost per day (95% CI): I = £204.6 (91.5-118.4), C = £104.9 (181.1-228.22) (MD £99.71, P < .001). Cost at 3 mo (95% CI): I = £3671.3 (3140.5-4231.3), C = £3876.9 (3224.51-4559.6) (MD −205.7, P > .65) *Bootstrap difference: −210.9 (−1025 to 635.5) Automated: Levine (2018)[47]: Care transitions measure: 3 (3-12), median (IQR): I = 12 (0), C = 12 (3) (P = .21). Picker questionnaire, 0-15: I = 15 (4), C = 13 (4) (P = .18). Global satisfaction score, 0-10: I = 10 (1), C = 10 (2) (P = .067). Recommend hospital score, 0-4: I = 4 (0), C = 4 (0) (P = 1) Levine (2019)[48]: Care transitions measure: 3 (3-12), median (IQR): I = 12 (1), C = 11 (3). Picker questionnaire, 0-15: I = 14 (2), C = 14 (3). Global satisfaction score, 0-10: I = 10 (1), C = 9 (1). Recommend hospital score, 0-4: I = 4 (0), C = 4 (0) Manual: Hernandez (2003)[45] - Satisfaction with care: I = 8, C = 7.5 (P = .03) Shepperd (2021)[55]: Satisfaction, % yes always: I = 493 (94.4%), C = 218 (89%) (ARR 1.01, 95% CI 0.99-1.03; P = .59) Unspecified: Caplan (1999)[40]: Patient satisfaction, 1-4, mean (95% CI): I = 1.1 (1.0-1.2), C = 2.0 (1.7-2.3) (P < .0001) Corwin (2005)[41]: Satisfaction with care: I = 96%, C = 96% (P = .12).

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Table 4 (*continued*)

Outcome	Number of Studies	Method of Data Synthesis	Effect of Intervention/Narrative Summary	Certainty of the Evidence (GRADE)	Individual Study Data
					Satisfaction with location: I = 93%, C = 66% ($P < .001$). Preference of location (hospital, community, no preference): I = 5%, 86%, 9%; C = 31%, 35%, 34% ($P < .0001$) Ricauda (2008)[53]: Satisfaction very good/excellent at discharge: I = 94%, C = 88% ($P = .83$) Richards (2005)[54]: Satisfaction with care, very happy: I = 100%, C = 60% ($P = .001$) Wilson (1999)[60]: Patient satisfaction score, 2 wk or discharge, 0-18, median (IQR): I = 15 (13-16.5), C = 12 (11-14) ($P < .0001$)
Relative or carer satisfaction	3	Data synthesis not performed, narrative summary of other data	Relative or carer experience of the care received is reported in 3 studies (all with an unspecified approach to vital sign monitoring). This is either reported as an overall satisfaction score, or a change in stress scale score from admission to discharge. Data were insufficient to carry out further analysis.	NA	Unspecified: Caplan (1999)[40]: Carer satisfaction score, 1-4, mean (95% CI): I = 1.1 (1.0-1.2), C = 1.9 (1.4-2.4) ($P = .0001$) Ricauda (2008)[53]: Change in Relatives' Stress Scale score, mean (SD): I = 4.6 (5.6), C = 2.6 (6.1) ($P = .16$) Tibaldi (2009)[58]: Relative Stress Scale score on admission, mean (SD): I = 25.4 (16.6), C = 17.1 (10.8) ($P = .003$). Relative Stress Scale score on discharge: I = 22.4 (15.8), C = not reported
Clinician satisfaction	1	Data synthesis not performed, narrative summary of other data	Clinician experience of the care received is reported in 1 study (unspecified approach to vital sign monitoring). This is reported as the overall GP satisfaction score. Data were insufficient to carry out further analysis	NA	Unspecified: Caplan (1999)[40]: GP satisfaction score, 1-4, mean (95% CI): I = 1.7 (1.4-2.0), C = 1.8 (1.4-2.2) (ns)

ARR, adjusted risk ratio; HR, hazard ratio; MD, mean difference; NA, not applicable; PT/OT, physical therapist / occupational therapist; QALY, quality-adjusted life year; SF-12, 12-Item Short Form Health Survey; SF-36, 36-Item Short Form Health Survey.

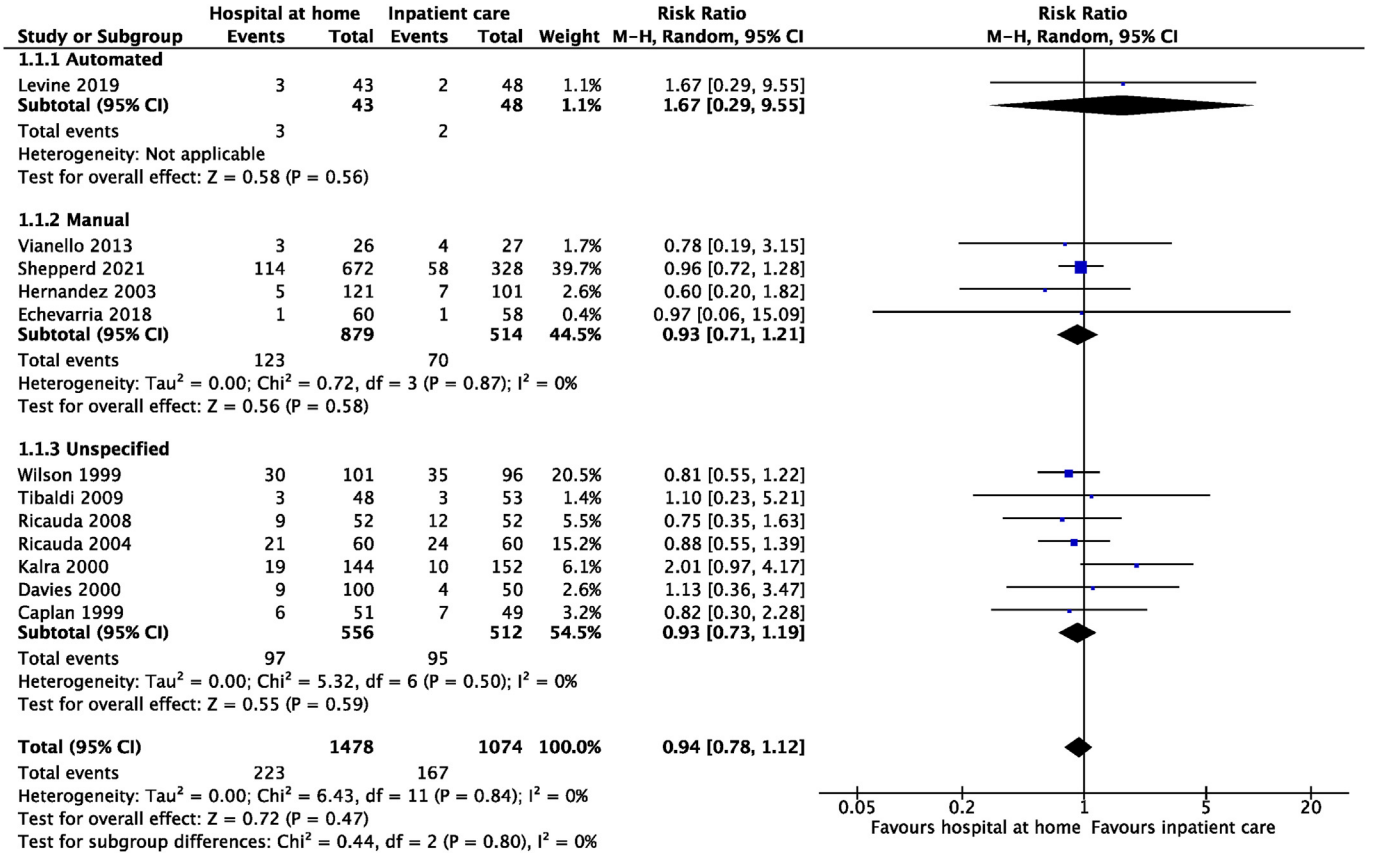

Fig. 3. Forest plot of HAH vs inpatient care for mortality (0-6 months).

of the data and the heterogeneity in follow-up periods between studies limits the certainty of the evidence presented. The latter was considered preferable to further stratification or narrowing of time intervals by allowing larger data sets given the small number and scale of included studies.

The findings of this review offer a number of key insights for the design of future clinical studies and implementation of vital sign monitoring in admission avoidance. First, it is essential that remote monitoring approaches meet recommendations on technology standards and are fully reported to allow detailed understanding of this component of the HAH intervention. This should include a description of the technologies used in relation to current recommendations and the protocol for remote monitoring (including the equipment and devices used, type of data collected, procedures for ensuring optimal data acquisition, frequency and method of data collection, arrangements for data transmission and mitigating loss of data, ways in which the data are displayed, and process for clinical review of data). This review has also highlighted the importance of future studies considering the use of automated vital sign monitoring using wearable devices and of comparing this approach to manual monitoring within the same HAH model. To date this evidence is limited, especially given the potential benefits offered by this technology and its availability.

Opportunities for remote monitoring to impact on clinical care include decisions on the allocation of home visits, escalation of care to hospital admission or discharge from care, requirement for additional diagnostic procedures, and changes to therapeutic management. Patient eligibility for trials evaluating remote monitoring should be based on criteria offering important individual and health care service benefits, for example, to test systems for home management during an acute illness that would otherwise require inpatient care. These criteria may be informed by the requirement of diagnostic tests or therapeutics capable of being administered at home. Measuring the subsequent use of resources (including diagnostics, therapeutics, and visiting) will help establish the impact of remote monitoring on the proficiency and capacity of services. Additional key aspects to consider is the reliability of continuous data collection and transmission over the required monitoring period and the subsequent risk-stratified or trend-based clinical alerting algorithms. Inaccuracies have the potential to impact safety and resource allocation by providing false reassurance of a patient's status or triggering unnecessary clinical review.

Finally, this review highlights the questions relating to the model of vital sign monitoring as an alternative to hospital admission that remain unanswered. In the included studies, monitoring protocols evidenced for hospital use were frequently applied directly to HAH. It may be that a better approach to automated remote monitoring could be derived from understanding basic principles of monitoring, existing related research in the field, and further observational research. As remote vital sign monitoring is being increasingly and variably deployed in HAH services, there is a pressing need to understand the impact of these systems. The recruitment of larger numbers of patients into remote vital sign monitoring studies are needed to establish their efficacy and effectiveness with more certainty. Future research alongside recent advances in technologies have the potential to reimagine the current model of monitoring in HAH care, in as yet unknown directions. For example, identifying unique patterns in continuous data that reliably correlate to real-time changes in the clinical status of patients managed at home could have significant value, and be feasible to implement through the use of wearable devices.

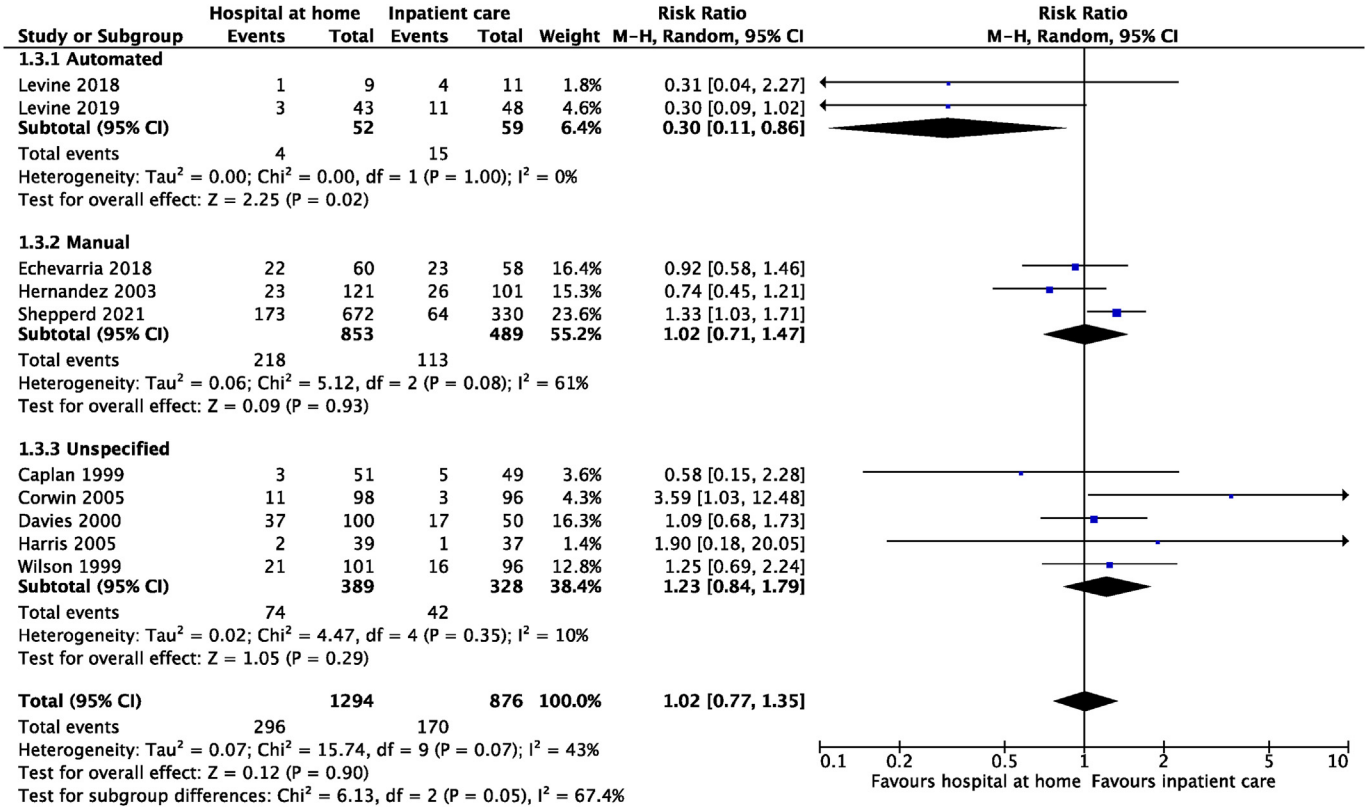

Fig. 4. Forest plot of HAH vs inpatient care for readmission to hospital (0-3 months).

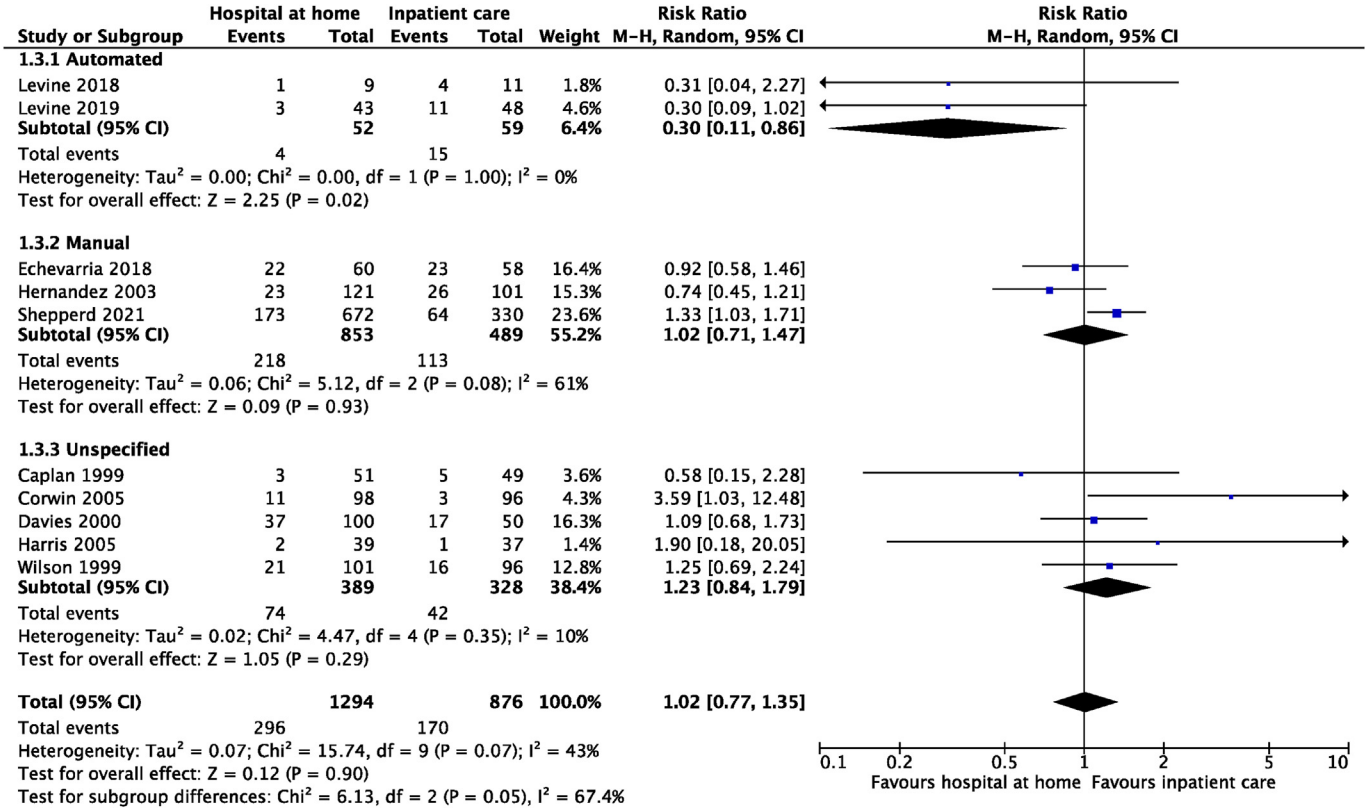

Fig. 5. Forest plot of HAH vs inpatient care for length of stay.

Conclusions and Implications

In conclusion, this review characterizes the existing vital sign monitoring approaches used in HAH studies for admission avoidance, highlighting gaps in the reporting and evidence base informing their application. It suggests the evaluation of continuous monitoring in HAH RCTs is limited, despite the potential benefits and expanding use in clinical practice. The findings of this review offer a number of key insights and inform recommendations for the design of future clinical studies.

Disclosure

The authors declare no conflicts of interest.

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