Remote home monitoring (virtual wards) during the COVID-19 pandemic: a systematic review

Cecilia Vindrola-Padros (0000-0001-7859-1646), Kelly E Singh (0000-0002-4513-1026), Manbinder S Sidhu (0000-0001-5663-107X), Theo Georghiou (0000-0001-9532-876X), Chris Sherlaw-Johnson (0000-0002-4851-6060), Sonila Tomini (0000-0002-4241-2121), Matthew Inada-Kim (0000-0001-6026-2246), Karen Kirkham, Allison Streetly (0000-0002-7588-9276), Naomi J Fulop (0000-0001-5306-6140)

Cecilia Vindrola-Padros, Senior Research Fellow, Department of Targeted Intervention, University College London (UCL), Charles Bell House, 43-45 Foley Street, London, W1W 7TY, United Kingdom, c.vindrola@ucl.ac.uk.

Kelly Elizabeth Singh, Evaluation Fellow, Health Services Management Centre, School of Social Policy, University of Birmingham, Park House, University of Birmingham, Edgbaston, Birmingham, B15 2RT, UK, k.e.singh@bham.ac.uk.

Manbinder S Sidhu, Research Fellow, Health Services Management Centre, School of Social Policy, University of Birmingham, Park House, University of Birmingham, Edgbaston, Birmingham, B15 2RT, UK, m.s.sidhu@bham.ac.uk.

Theo Georghiou, Senior Fellow, Nuffield Trust, 59 New Cavendish Street, London, W1G 7LP, UK, theo.georghiou@nuffieldtrust.org.uk.

Chris Sherlaw-Johnson, Senior Fellow, Nuffield Trust, 59 New Cavendish Street, London, W1G 7LP, UK, chris.sherlaw-johnson@nuffieldtrust.org.uk

Sonila Tomini, Research Fellow, UCL Department of Applied Health Research, University College London, Gower Street London, WC1E 6BT, UK, s.tomini@ucl.ac.uk

Matthew Inada-Kim, Consultant Acute Physician, Hampshire Hospitals NHS Foundation Trust, Clinical Director Patient Safety & Digital, Wessex Academic Health & Science Network
National COVID Clinical Reference groups- Primary care, Secondary care, Care homes National Clinical Lead Deterioration & National Specialist Advisor Sepsis, NHS England and NHS Improvement, McGill ward, Royal Hampshire County Hospital, Romsey Road, Winchester SO21 1QW, UK, matthew.inada-kim@nhs.net.

Karen Kirkham, General Practitioner NHS Dorset, Integrated Care System Clinical Lead, NHSE/I Senior Medical Advisor Primary Care Transformation, Dorset CCG, Vespasian House, Barrack Rd, Dorchester, Dorset DT1 7TG, UK, Karen.kirkham@dorsetccg.nhs.uk.

Allison Streetly, Department of Population Health Sciences Faculty of Life Sciences & Medicine, King's College London SE1 1UL, UK, Deputy National Lead Healthcare Public Health, Public Health England 133-155 Waterloo Rd, London SE1 8UG & Senior Lecturer in Public Health Kings College London, allison.streetly@phe.gov.uk

Naomi J Fulop, Professor of Health Care Organisation and Management, UCL Department of Applied Health Research, University College London, Gower Street London WC1E 6BT, UK, n.fulop@ucl.ac.uk

Corresponding author:
Dr Cecilia Vindrola
Senior Research Fellow
Department of Targeted Intervention
University College London (UCL)
Charles Bell House
43-45 Foley Street
London
W1W 7TY
UK
c.vindrola@ucl.ac.uk

ABSTRACT

Objectives: The aim of this review was to analyse the implementation and impact of remote home monitoring models (virtual wards) during COVID-19, identifying their main components, processes of implementation, target patient populations, impact on outcomes, costs and lessons learnt.

Design: The review was designed as a rapid systematic review to capture an evolving evidence base. We used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.

Setting: The review included models led by primary and secondary care across seven countries.

Participants: 17 examples of models were included in the review.

Main outcome measures: Impact of remote home monitoring on virtual length of stay, escalation, emergency department attendance/reattendance, admission/readmission and mortality.

Results: The aim of the models was to maintain patients safe in the right setting. Most models were led by secondary care and confirmation of COVID-19 was not required (in most cases). Monitoring was carried via online platforms, paper-based systems with telephone calls or (less frequently) through wearable sensors. Models based on phone calls were considered more inclusive. Patient/carer training was identified as a determining factor of success. We could not reach conclusions regarding patient safety and the identification of early deterioration due to lack of standardised reporting and missing data. Economic analysis was not reported beyond how the resources were used.

Conclusions: Future research should focus on staff and patient experiences of care and inequalities in patients' access to care. Attention needs to be paid to the cost-effectiveness of the models and their sustainability, evaluation of their impact on patient outcomes by using comparators and the use of risk-stratification tools.

Protocol registration: The review protocol was published on PROSPERO (CRD: 42020202888).

INTRODUCTION

COVID-19 has rapidly spread across the world, leading to high rates of mortality and unprecedented pressure on healthcare systems. Delays in the presentation of patients with COVID-19 has led to patients arriving as emergencies with very low oxygen saturations, often without accompanying breathlessness ('silent hypoxia')[1]. These delayed presentations of severe COVID-19 led to extended hospital admissions for patients, often requiring invasive treatment and potential admission to intensive care units (ICU) or death[2]. Remote home monitoring models (sometimes referred to as 'virtual wards') have been established to: 1) avoid unnecessary hospital admissions (appropriate care at the appropriate place), and 2) escalate cases of deterioration at an earlier stage to avoid invasive ventilation and ICU admission[3]. Some of these models have integrated the use of pulse oximetry to monitor oxygen levels and identify and treat cases of 'silent hypoxia'[2].

Remote home monitoring models have been implemented in the US, Australia, Canada, the Netherlands, Ireland, China and UK, with some variation in the frequency of patient monitoring, modality (a combination of telephone or video calls and use of applications or online portals), patient admission criteria, staffing models used for patient monitoring and level of clinical oversight, and use of pulse oximetry[4-8].

There is a paucity of published literature on the models of care developed to implement remote home monitoring across different healthcare contexts during the COVID-19 pandemic, the experiences of staff implementing these models and patients receiving care, the use of data for monitoring progress, resources required, as well as the impact of these models on clinical, process and economic outcomes. The aim of this review was to address these gaps by analysing the remote home monitoring models implemented during COVID-19, their main components, processes of implementation, target patient populations and lessons learned. We sought to identify evaluations of these models and their outcomes.

METHODS

Design

We followed the review method proposed by Tricco et al.[9]. The rapid review method follows a systematic review approach but proposes adaptations to some of the steps to reduce the amount of time required to carry out the review. We used a large multidisciplinary team to review abstracts and full texts, and extract data; in lieu of dual screening and selection, a percentage of excluded articles was reviewed by a second reviewer, and software was used for data extraction and synthesis[9].

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement[10] to guide the reporting of the methods and findings. The review protocol was registered with PROSPERO (CRD: 42020202888, registered 6 August 2020).

Research questions

The review sought to answer the following questions:

1. What are the aims and designs of remote home monitoring models?
2. What are the main stages involved in remote home monitoring for COVID-19?
3. What are the patient populations considered appropriate for remote monitoring?
4. How is patient deterioration determined and flagged?
5. What are the expected outcomes of implementing remote home monitoring?
6. What is their impact on outcomes and costs?
7. What are the benefits and limitations of implementing these models?

Search strategy

We used a phased search approach[9]. We carried out a series of search phases where we gradually added search terms based on the keywords used in the literature we identified. Appendix 1 includes the strategies used for these waves, including the final search strategy. We searched for literature indexed in the following databases: MEDLINE, CINAHL PLUS, EMBASE, TRIP, medRxiv and Web of Science. Initial searches were carried out on 9 July 2020 and updated on 21 August 2020 and 21 September 2020. Results were combined into Mendeley and duplicates were removed. The reference lists of included articles were manually screened to identify additional relevant publications.

Study selection, inclusion and exclusion criteria

One researcher (CVP) screened the articles in the title phase, and additional researchers (KS) cross-checked exclusions in the abstract and full-text phases (KS, MS). Disagreements were discussed until consensus was reached. The inclusion criteria used for study selection was: 1) focus on the monitoring of confirmed or suspected patients with COVID-19), 2) focus on pre-hospital monitoring, monitoring after Emergency Department (ED) presentation and step-down wards for early discharge, 3) focus on monitoring at home (excluding monitoring done while the patient is in healthcare facilities), and 4) published in English. Due to the rapidly expanding evidence-base on COVID-19, we included a wide range of publications (i.e. feature articles, descriptions of services) and did not limit the selection to evaluations of remote home monitoring.

Data extraction and management

The included articles were analysed using a data extraction form developed in REDCap (Research Electronic Data Capture) that extracted data on: the design and general characteristics of the model, patient populations, main reported process and clinical outcomes and its potential economic impact. The form was developed after the initial screening of full-text articles. It was then piloted independently by two researchers using a random sample of five articles (CV and KS). Disagreements were discussed until consensus was reached. The data extraction form was finalised based on the findings from the pilot. Data extraction was cross-checked by three researchers (TG, CSJ and ST).

Data synthesis

Data were exported from REDCap and the main article characteristics were synthesised. The information entered in free text boxes was exported from REDCap and analysed using framework analysis[11]. The initial categories for the framework were informed by our research questions but we were also sensitive to topics emerging from the data.

Quality assessment

Due to the descriptive nature of the articles and lack of data in relation to study design, we did not assess the quality of the studies.

RESULTS

The initial search yielded 902 articles (Figure 1). These were screened based on the title and abstract and type of article, resulting in 155 articles for full-text review. Full-text review of these articles led to 11 articles that met the inclusion criteria (reasons for exclusion can be found in Figure 1). Three additional articles were identified by reviewing the bibliography and two articles were identified in an updated search carried out on 21 September 2020, ultimately leading to 16 articles (including 17 examples of remote home monitoring) included in the review. We excluded articles that focused on monitoring that took place within hospital settings (i.e. ICU) or for other non-COVID-19 related conditions.

INSERT FIGURE 1 HERE

Characteristics of the included remote home monitoring models

Eight of the remote home monitoring models were implemented in the US, three in the UK, two in Canada, and one each in The Netherlands, China, Ireland and Australia. Seven of the articles described the service, two were identified as evaluations, five as observational studies, one as a feasibility study and one (containing the example of two models) was a news feature (with a limited description of the services). Twelve of the examples were published in peer-reviewed journals and five were published in the form of preprints. The main characteristics of the included remote home monitoring examples are summarised in Table 1.

INSERT TABLE 1 HERE

Aims and main designs of remote home monitoring models

The primary aim of the remote home monitoring models was to enable the early identification of deterioration for patients self-managing COVID-19 symptoms at home (including those who had not been admitted to hospital as well as those who had been discharged). The programme theory guiding these models was that if patients were able to take the required regular observations whilst remaining at home and communicate these to the healthcare professionals responsible for their care, then cases of deterioration could be identified early and acted upon. These actions could include changing their treatment protocol, referring them to primary care or to the emergency department for assessment and potential admission to hospital. A secondary aim of the models was their use to reduce the rate of hospital infection and demand for beds in the acute care sector, where admission to hospital could be prevented for patients considered suitable to be managed at home and those who had been admitted to hospital could be discharged earlier but continue under the remote care of a medical team (a team that varied in composition depending on the model).

Most of the remote home monitoring models included in the review (15 examples out of 17) were led by teams in secondary care. Two examples were primary care led. Nine of the models functioned as pre-admission wards, in the sense that they sought to prevent the admission of patients to hospital or to identify cases of deterioration early (so those who should be referred could be admitted to hospital with lower rates of acuity). Three of the models functioned as "step-down" wards, that is, they were designed for patients who had been admitted to hospital (including ICU) where the medical team had identified that they could be discharged and safely monitored at home until their symptoms improved. Five models functioned as pre-admission and step-down wards, organised according to two separate pathways.

Patient populations considered appropriate for remote monitoring

Most of the models had broad criteria for the eligible patient population, defining the patient group as adult (over 18 yrs.) patients with COVID-19 symptoms (suspected and confirmed cases). Five of the models limited referrals to COVID-19 cases confirmed through testing[6 12-15]. The model described by Hutchings et al.[6] excluded patients over 65 years with significant comorbidities. Shah et al.[16] excluded pregnant women and only included patients with SpO_2 above 92% at initial assessment. We did not find any examples targeting socially and economically disadvantaged groups (although some models included support from social workers and mental health professionals)[4 17]. It is important to highlight that the size of the patient cohorts varied considerably (see Table 2 for patient numbers) and ranged from 18 patients to 6853. The models with the highest numbers of patients were implemented in the US. The comorbidities mentioned with greater frequency were hypertension, asthma and obesity.

Table 2. Main characteristics of monitored patients

	Number patients	Mean age	Most common comorbidities
Agarwal	97	Inconsistencies in reporting in the article (48.6, 43.6 and 43.8)	Asthma, hypertension, dyslipidemia and anxiety
Annis	2255	median 38*	NS
Grutters	33	57	NS
Margolius	4213	42	NS
Lam	50	median 44	hypertension, malignant disease
Medina	878	NS	NS
O'Keefe	496	47.6	hypertension, obesity, asthma diabetes
Shah	77	median 44	obesity and hypertension
Xu	48	median 37.5	NS
Hutchings	162	median 38	NS
Kricke	6835	47**	NS
Ford	154	NS	NS
Maghrabi	300	57	Hypertension
Thornton1 (Watford)	1042	NS	NS
Thornton2 (Reading)	244	NS	NS
Morgan	2348	40-49	NS
O'Carroll	18	median 48	NS

*For the subset of 1496 patients who completed the programme; ** for a subset of 6,006 who completed a survey
NS=not specified

Stages of remote home monitoring
The articles described five main stages in remote home monitoring for COVID-19: 1) referral and triage to determine eligibility, 2) onboarding of patient to remote home monitoring service (provision of information to patient and/or carer on monitoring process, mechanisms for escalation and self-care), 3) monitoring (including recording of observations, communication of the information, assessment of the information by the medical team), 4) escalation (if required), and 5) discharge from the pathway.

Patient information recorded at triage included:

- Patient demographics (age, sex, race/ethnicity, insurance type in the models in the US)
- Clinical variables (clinical signs and symptoms, medical history and medications)
- Health data for risk assessment and vital signs data (body temperature, heart rate, respiratory rate and oxygen saturation)

Three studies included some degree of detail in relation to the categorisation of patients in relation to risk[14 17 18]. The article by O'Keefe and colleagues[12] described and evaluated a risk assessment model based on age, medical history and symptom severity. This model was able to identify the need for hospitalisation in initially non-severe COVID-19 patients.

In six of the examples included in the review, monitoring was based on patient record of observations using a paper-based system and then communicating the information to a member of the medical team by telephone (see Table 1). Nine of the examples relied on the use of an online mechanism, either through an app or online form. One example offered patients a telephone or an app option[19]. Another example relied on the use of wearable sensors to continuously monitor temperature readings and transfer these to the medical team[6]. Ten of the models relied on the use of pulse oximetry from the beginning of implementation, four models did not use pulse oximetry, one model added pulse oximetry three weeks after implementation and two articles indicated that the use of pulse oximetry was being considered in the near future.

Escalation was actioned depending on pre-established thresholds. Not all articles have reported the thresholds for escalation and most only refer to the worsening of symptoms. Shah et al.[16] indicated that patients on their remote home monitoring pathway were flagged as deteriorating if reporting SpO_2 below 92% after a double reading. Xu et al.[20] used a SpO_2 reading of below 93% or BP less than 90/60 mmHg. Some of the examples included in the review established safety-netting options in cases when patients could not be reached via phone such as calling the police so they could visit the patient at home[6].

Most patients were followed-up until their symptoms improved or the patient opted out of the pathway. Medina et al.[13] reported following up patients on the step-down pathway for 7 days post-discharge from hospital and those on the pre-admission pathway for 14 days. Shah et al.[16] followed-up patients on their pre-admission pathway for 7 days. Hutchings et al.[6] referred patients to their GP for follow-up after discharging them from the remote home monitoring pathway.

Expected outcomes of implementing remote home monitoring
The outcomes recorded in each remote home monitoring model are listed in Table 1. They can be grouped in three main categories: 1) process outcomes related to the remote home monitoring pathway, 2) process outcomes related to secondary care and 3) patient outcomes (including clinical and experience). Process outcomes related to the remote home monitoring pathway included: time from swab to assessment, time to escalation and ambulance attendance/emergency activation (i.e. calling 999 or 911). Process outcomes related to secondary care included length of stay. Outcomes considered at the patient level included: emergency department attendance/reattendance, hospital admission, ICU admission, readmission, mortality, ventilation or non-invasive ventilation needs, and patient satisfaction.

Impact on outcomes
It was difficult to carry out an analysis of the impact of remote home monitoring across all examples because not all articles reported data on the same outcomes (Table 3). Mortality rates were low, admission or readmission rates ranged from 0 to 29%, and ED attendance or reattendance ranged from 4 to 36%. Four of the models reported data on patient feedback, with high satisfaction rates[5 8 18 21].

Remote home monitoring process outcomes were only included in six of the articles, with time from swab to assessment ranging from 2 to 3.7 days[12 17 19] and virtual length of stay from 3.5 days to 13 days (see Table 3). Only one article presented findings on reduction in length of stay, calculated at 5 days fewer per patient[21].

Table 3. Impact of remote home monitoring on selected outcomes

	virtual LoS	Escalation	ED attendance/ reattendance	Admission/ readmission	Mortality
Agarwal	8 days (median)	5.10%	4.2%	0	NS

Annis	NS	NS	4.0%	0.6%	NS
Grutters*	13 days (mean)	18 patients reassessed in hospital	NS	9%**	0
Margolius*	NS	NS	7%	1%	NS
Lam	12.5 days (only for 52% of patients)	12%	NS	8%	0
Medina	NS	10%	NS	2%, 3%**	9 patients but denominator is unclear
O'Keefe	13.1 days	NS	NS	7.1%	NS
Shah	NS	25%	36%	29%	2.6%
Xu	NS	NS	NS	NS	0
Hutchings	8 days (only for 62 of the patients in the sample)	5 patients	2.5%	1.9%	0
Kricke	NS	NS	7.7%	NS	NS
Ford	NS	14.3% referred to physician review; 3.9% physician to patient call; 2.6% to ED and admitted	2.6%	2.6%	NS
Maghrabi	3.5 days (median)	NS	13%	9%**	0.66%
Thornton1 (Watford)	NS	NS	NS	NS	NS
Thornton2 (Reading)	NS	NS	11.9%	7.4%	0
Morgan	12.7 days (mean)	16.9% escalated to nurse review	7.9%	3.4%	NS
O'Carroll	12 days (median)	NS	NS	4 patients	NS

*included data for patients on remote home monitoring pathway, **refers to readmission in cases of step-down wards, LoS=length of stay, ED= emergency department, NS= not specified.

The economic impact
None of the selected studies for this rapid review provided any form of economic analysis, though some of them mentioned the potential for cost savings based on the utilisation of virtual monitoring programs for other treatments in similar settings[14 21]. Some of the selected studies highlighted the fact that, during the pandemic, the intervention used existing resources and staff that were made available due to the emergency situation[7 12 14 22]. However, they also highlighted that, with the return to normal workloads in the health care system, a question of allocation of resources and sufficient staffing still remains.

DISCUSSION
In this article we have sought to make a contribution to the rapidly growing evidence-base on the use of remote home monitoring models for patients with confirmed or suspected COVID-19 (see box 1 for key lessons). The review has pointed to factors that need to be taken into consideration in relation to the design of these models. Most of the models included in the study were led by secondary care but some authors argued that coordination between primary and secondary care could facilitate the implementation of remote home monitoring pathways[5 7 13]. Primary care led models might be more adaptable to evolving patient and system needs and easier to replicate in contexts with limited secondary care access and

capacity[17]. Three models integrated mental health and social care support during and after patient monitoring, highlighting a wide range of patient needs[6 13 17].

Box 1. Key lessons in the implementation of remote home monitoring models during the COVID-19 pandemic

> - It is important to consider remote home monitoring models as an approach to maintain patients safe in the right setting.
> - The use of apps for monitoring allowed the follow-up of a higher number of patients (compared to paper-based models), but some of the studies indicated that models based on telephone calls were more inclusive (i.e. including patients without internet access or technological literacy).
> - Patient/carer training was identified as a key determining factor of the success of these models.
> - Coordination between primary and secondary care facilitated implementation
> - Primary care led models were considered, in some cases, as more adaptable to evolving patient and system needs, and easier to replicate in contexts with limited secondary care access and capacity.
> - A few models have integrated mental health and social care support during and after patient monitoring, highlighting a wide range of patient needs.

Even though several of the examples used apps and other types of online platforms, discussions in relation to the use of health technology were limited. The use of apps for monitoring allowed the follow-up of a higher number of patients (compared to paper-based models) but some of the studies indicated that models based on telephone calls were more inclusive (i.e. including patients without internet access or technological literacy)[19]. Patient experience was captured in some of the examples we reviewed[8 21] but the analysis of patient experience was limited. An analysis of patient experience and engagement is important as the literature on the use of remote patient monitoring for other conditions has demonstrated that higher levels of patient engagement with remote patient monitoring technology are associated with better patient outcomes[23].

Similarly to other reviews on remote patient monitoring in other conditions, another limitation was the lack of attention placed on the implementation of the models and the failure to identify the programme theories guiding their design, factors that acted as barriers and facilitators and the extent to which the pathways were implemented according to their original plans[24]. This could be due to the limited evidence on COVID-19 and the management of patients with this disease at the time of designing and implementing these models as well as the general limited use of programme theories in the design of healthcare interventions that has already been documented in the literature[25].

Emerging international evidence has indicated that lower thresholds for oxygen saturation, are associated with worse patient outcomes[2 26]. In the case of our review, even though some authors argued that pulse oximetry identified the need for hospitalisation when using a cut-off of 92%[16], we could not reach conclusions in relation to patient safety and the degree to which remote home monitoring models can conclusively identify cases of deterioration at an earlier stage in the disease trajectory. The main reasons were lack of standardised reporting across articles in relation to these outcome measures and how these were measured, as well as the limitation that none of the articles used comparators.

Issues with using pulse oximetry were also highlighted such as: patient physiological measures needed to be recorded several times a day to correctly identify cases of deterioration, some remote home monitoring examples used standardised home pulse oximeters to avoid variability between different brands, pulse oximetry readings were made less accurate by nail polish, severe anaemia, hyperbilirubinemia, hemoglobinopathies, or

poor peripheral perfusion from severe vasoconstriction or poor cardiac output[16 27]. Some authors also argued that patient training was a key determining factor of the success of health information technology as it ensured readings and other observations were carried out accurately[6]. Remote home monitoring needed to be seen as an approach to maintain patients safely in the right setting rather than as an admission avoidance model.

Remote home monitoring for COVID-19 patients was expected to have a positive economic impact, mainly due to costs savings in staff time and PPE utilisation, avoidance of infection of frontline medical staff and reduced hospitalisations[14 21]. However, the economic evidence in relation to these was limited. None of the selected studies included any form of economic analysis. The selected studies have, however, raised the issue of resource allocation and funding, especially when it comes to the continuity of such programs after the first emergency situation. Most of the staff who worked on remote monitoring interventions for COVID-19 came from other services and the resources used were already existing. Yet, with the return to normal workloads, providing sufficient staff and enough resources may become a problem. Previous studies have indicated that remote monitoring in itself has contributed to increased efficiency in the use of resources (such as reduction in length of stay, increasing bed availability without compromising patient care safety, etc.)[15 21]. A complete economic analysis in this context could indicate if remote home monitoring for COVID-19 patients is a cost-effective intervention and could help inform accurate planning of the needed resources and staff. This economic analysis would also need to include costs and benefits beyond the actual remote home monitoring models, a reliable control group, as well as a longer follow up period.

This review has a series of limitations. The last search was carried on 21 September 2020, so any articles published after this date were not included. We have included preprints as a way to address delays produced by external review and publication. Furthermore, although we employed multiple broad search terms, it is possible that we missed articles that did not use these terms. Due to the variability in study designs and the descriptive nature of the articles we did not assess these for quality using standardised tools for assessment. However, we feel it is important to note that we found several cases of missing data and inconsistencies in the reporting of evaluations that would lead to low quality ratings.

The review pointed to several future areas of research. These could include an analysis of patient experience, beyond measures of satisfaction and the exploration of potential inequalities in patients' access to remote home monitoring models or patients' difficulties interacting with technology. Technological barriers have been reported in other studies of remote home monitoring and should not be overlooked when exploring the experiences of patients with COVID-19[28 29]. Additional attention needs to be paid to the processes used to implement these models and how these might vary based on the healthcare sector, patient population, size, wave of the pandemic and approaches used for triage, monitoring and escalation. As mentioned earlier, primary care might need to play a more central role in the coordination of remote patient monitoring models, providing more holistic care for patients and reducing the demand on hospital services[30]. The evaluation of remote home monitoring, considering its impact on patient outcomes through the use of comparators is also required. We also need to consider the sustainability of these models during multiple epidemiological peaks, compare different approaches to remote home monitoring and assess their cost-effectiveness.

Table 1. Characteristics of the included remote home monitoring examples

	Author	Country	Type of study and article	Type of model	Terms	Sector	Patient population	Triage process	Recorded patient info	TPatient reporting tool	Patient monitoring tool	Outcomes
1	Margolius	USA	Evaluation/ Preprint	Pre-admission	Telehealth services	PC	C19 symptoms	Patient referred to teleconsultation and follow-up call made 24 hours after	*Data for risk assessment*: age, sex, race/ethnicity, insurance type, smoking status and clinical variables directly relevant to understanding the social epidemiology of the COVID-19 hotline (symptom protocols, visit disposition, visit diagnoses). *Data for monitoring*: change in symptoms (including temperature), basic living needs	Paper-based	Telephone call	(1) emergency room visit likely related to COVID-19 subsequent to hotline telehealth visit, (2) hospitalization due to COVID-19 subsequent to hotline telehealth visit, (3) SARSCoV-2 PCR test ordered subsequent to telehealth visit, and (4) positive SARS-CoV-2 PCR test subsequent to telehealth visit.
2	Maghrabi*	UK	Description of the service/ Preprint	Step-down ward	Virtual ward	SC	Discharged patients with suspected or confirmed COVID-19	Patients where there were concerns about oxygenation were discharged with a pulse oximeter and onboarded on to the virtual ward.	*Data for monitoring:* symptom improvement, stability or deterioration (including oxygen saturation)	Patients received daily phone calls and asked standardised questions.	Patients referred through an electronic form on the EHR, monitoring data were inputted directly on the EHR and auto-populated a dashboard.	LoS on virtual ward and in hospital, O₂ requirements, readmission, reattendance, mortality and patient satisfaction.
3	Thornton1 (Watford)*	UK	Description of the service in news feature/ Published article	pre-admission and step-down	Virtual ward	SC	Patients presenting at ED with symptoms and admitted patients who needed additional monitoring at the point of discharge	Patient assessed in ED and triaged to virtual ward with pulse oximeter. Patients where there were concerns about oxygenation were discharged with a pulse oximeter and onboarded on to the virtual ward.	*Data for risk assessment*: patient-reported data (clinical signs and symptoms, medical history and medications) *Data for monitoring*: symptoms, temperature, and their oxygen level.	Online: App (Medopad) + phone calls (phase 1 of the service)	Medopad app	ED reattendance, admission/readmission, mortality
4	Thornton2 (Reading)*	UK	Description of the service in	pre-admis	Virtual ward	SC	Patients presenting at	Patient assessed in ED and triaged to	*Data for risk assessment*:	Paper-based (patient recorded information	Phone call with medical team.	ED reattendance, admission/readmission,

#	Author	Country	Study type/Source	Setting	Service	SC	Population	Risk assessment process	Data	Online/mode	Monitoring	Outcomes
			news feature/ Published article	sion and step-down			ED with symptoms or referred from primary care. Also included admitted patients who needed additional monitoring at the point of discharge.	virtual ward with oximeter. Patients where there were concerns about oxygenation were discharged with a pulse oximeter and onboarded on to the virtual ward.	patient-reported data (clinical signs and symptoms, medical history and medications) **Data for monitoring**: symptoms, temperature, oxygen saturation level.	at home and reported it to the medical team over the phone)	Patients asked to do stress test and report O_2 sats level	mortality, patient satisfaction
5	Hutchings*	Australia	Observational study/ Preprint	Pre-admission	Virtual health care, remote patient monitoring	SC	Patients in whom C19 is detected (certain inclusion and exclusion criteria apply)	Patients attend COVID-19 testing clinic, those in whom the virus is detected are referred to the virtual care centre by the local public health unit. The care centre conducts an initial assessment to ascertain suitability for virtual health care – this is done by telephone	**Data for risk assessment**: patient-reported data (clinical signs and symptoms, medical history and medications) **Data for monitoring**: vital signs - respiratory rate, oxygen saturation, pulse rate and temperature, assessment of other symptoms and signs of deterioration assessed by video call	Online: Wearable temperature monitor provides continuous temperature monitoring, which feed into a dashboard. Pulse oximeter readings read directly from the device. Video consultations used to confirm vital signs collected by wearable devices.	Wearable temperature monitor provides continuous temperature monitoring, which feed into a dashboard. Patients monitored three times a day, including a videoconference twice every 24 hours. Video consultations comprised most contacts with telephone consultations making up the remainder.	Ambulance attendance, ED attendance, ED admission, mortality
6	Kricke	USA	Description of service/ Published article	Pre-admission	Home monitoring, outpatient monitoring, community based virtual care	SC	Patients added to the registry were those with pending/indeterminate/positive COVID-19 test or presumed presence based on clinical criteria. Later began only	States only nurses from COVID-19 triage phone line, ED staff, and hospital medicine staff were able to add patients to the registry.	**Data for risk assessment**: Evaluation of 10 symptoms – used a short questionnaire that captured the main domains of patients' symptoms and experiences. (symptoms - cough, shortness of breath, sore throat, muscle aches, trouble sleeping, lack of	Online: Enrolled patients with an electronic health record portal account receive a questionnaire invitation where they evaluate symptoms, those not enrolled in the patient portal (or who do not respond) are called.	They monitor and stratify responses to daily questionnaires, those with concerning symptoms are called. Calls used to evaluate symptoms, provide information and answer questions.	ED referrals (also anecdotal data about being provided education, comfort and getting 911 activation help).

#	Author	Country	Study type	Setting	Intervention type	SC	Population	Referral/enrolment	Data for risk assessment/monitoring	Platform	Monitoring action	Outcomes
							including those with positive COVID-19 test.		energy, feeling ill, fever, diarrhoea, stomach pain), patients were also asked how many analgesic/antipyretic tablets they are taking, symptoms of others in the household, and for a measured temperature. **Data for monitoring**: symptoms and temperature.			
7	Annis***	USA	Evaluation/ Published article	Pre-admission	Remote patient monitoring, telehealth	SC	Patients with confirmed or suspected COVID-19	Patients that were enrolled were either screened for COVID-19through virtual care platforms (phone, video, online) or at an ED or urgent care visit and referred. Providers were informed about the programme as a care option. Had a referral order within electronic health records to gather the patients' required information and they developed a batch process to automate enrolment. Then patients received an email with information on how to activate and begin the programme (optional).	**Data for risk assessment**: patient-reported data (clinical signs and symptoms, medical history and medications). **Data for monitoring:** Daily check in questions to monitor/assess symptoms, later updated to include question that assessed pulse oximetry data.	Online: GetWell Loop - daily check in questions for patients to assess their symptoms, patients could also send comments and questions through scrolling newsfeed. Patients could also call the Mhealth triage line for alerts or comments outside 8am-5pm (before they expanded the workforce to include 24/7 virtual care so alerts could be responded to out of hours).	GetWell Loop - symptom monitoring questions were monitored - concerning answers routed to dashboard for action by member of first responder team. Physicians would also text or call patients if an alert or comment was concerning/complicated.	Hospital admissions, ED visits. Patient satisfaction data also collected.
8	O'Keefe	USA	Observational study (retrospective cohort study)/ Preprint	Pre-admission	Telemedicine visits, virtual outpatient management, telephone monitoring	SC	Patients with positive COVID-19 PCR test	Patients with positive COVID-19 PCR test from screening clinics or ED were referred for enrolment in the Virtual Outpatient Management Clinic. For those enrolling in	**Data for risk assessment**: patient-reported data (clinical signs and symptoms, medical history and medications).	Patients received regular calls	Telephone - patients received regular calls, different levels of observation e.g. frequency of calls and duration, based on	Hospitalisation (metric: days to hospitalisation).

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No	Author	Country	Study type	Setting	Model	PC/SC	Population	Description	Data for risk assessment / monitoring	Technology	Monitoring	Outcomes
								the virtual clinic, risk assessment data were obtained during a scheduled telemedicine appointment.	**Data for monitoring:** Reported symptom data (including temperature).		assigned risk tier.	
9	Ford*	USA	Description of the service/ Published article	Pre-admission and step-down ward	Telehealth remote patient monitoring	SC	Patients with confirmed COVID-19	Used dedicated registry of COVID-19 patients - populated using the positive diagnostic test as the trigger (as well as with all patients using virtual urgent care for COVID-19 suspicions). All testing submitted through the site was pulled into the registry for potential enrolment in home monitoring as were all positive tests regardless of entry point (drive up, virtual urgent care, ED, inpatient admission or pre-op testing). Nurses could enrol, triage and follow patients - nurses contacted patients who tested positive and offered opportunity to enrol in programme.	**Data for risk assessment:** patient-reported data (clinical signs and symptoms, medical history and medications) **Data for monitoring:** Patient reported outcomes (PRO) survey – derived from validated community acquired pneumonia patient questionnaire (five item survey queries changes in patient reported dyspnea), later extended to include pulse oximetry (for select groups inc post hospitalisation) and digital thermometers (app also extended capabilities with Bluetooth pulse oximeters and digital thermometers).	Online: Via patient portal (Epic MyChart electronic health record) or app- nurse managers could choose which to prescribe.	Monitored responses to PRO through portal or app, nurses can reach out by phone if symptoms worsen.	Nurse to patient encounter, referral for physician review, physician call, referral to ED, hospitalisation.
10	Agarwal*	Canada	Observational study (retrospective cross-sectional study)/ Preprint	Pre-admission	Remote home monitoring model, virtual care	PC	Patients with COVID-19 (swab or presumed positive) felt to be high-risk based on age, comorbid illness and respiratory symptoms.	Patient attended PC and was triaged to low, moderate or high risk using clinical judgement. Follow-up virtual visits were booked with the resident or RN every 1-3 days based on risk. Program aimed to follow patients from time of referral up to	**Data for risk assessment:** Demographics, comorbidities, COVID status, risk of transmission, symptoms, oximeter readings, thermometer readings. **Data for monitoring:** symptoms, oximeter	Paper-based: Telephone calls directed by medical team but patients also had access to a dedicated on-call service 24-hours a day. Pulse oximeters and thermometers were couriered to patients.	Telephone or video visits, 7-days a week by an inter-professional, family medicine led team. Data entered into EPIC using a standardized electronic flowsheet. A	ED attendance, admission, referral to social worker.

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#	Author	Country	Study type	Setting	Intervention	SC	Inclusion criteria	Process description	Data	Platform	Monitoring	Outcomes
								14 days from symptom onset.	readings, thermometer readings.		dashboard cataloguing each patient in the program with their risk level for deterioration and active care issues was developed to facilitate daily team huddles.	
11	Xu	China	Observational study (retrospective cohort study)/ Published article	Pre-admission	Telemedicine system	SC	Confirmed or suspected cases of COVID-19	Patient attended hospital and was assessed for telemedicine system. The patient was given access to an online telemedicine form and a link to the WeChat app to the patient's mobile phone or by email.	**Data for risk assessment:** Demographics, clinical history, clinical manifestations, lab tests, CT images **Data for monitoring:** changes in symptoms (including temperature).	The patient was required to update their conditions on a daily basis using the telemedicine form. The patient joined a WeChat group to receive information and could set-up a one-to-one chat with the MDT.	Communication through telemedicine form and WeChat group.	ED attendance, admission, mortality, need for ECMO.
12	Medina*	USA	Service description/ Published article	Pre-admission and step-down	Home monitoring, home-based intervention	SC	Confirmed COVID-19 and risk factors: risk factors include age older than 60 or younger than 3, active immunosuppression, active cancer, end-stage renal disease on dialysis, diabetes, hypertension, coronary artery disease, heart failure with reduced ejection fraction, chronic lung	Patients are enrolled into the home monitoring program after an ambulatory virtual assessment with a clinician, or after hospital discharge for COVID-19. Patients receive an initial phone call with instructions. Patients from the hospital are monitored for 7 days and ambulatory patients for 14 days.	**Data for risk assessment**: patient-reported data (clinical signs and symptoms, medical history and medications). **Data for monitoring:** Symptoms, pulse oximetry readings, temperature.	Online: Patient records information on the MyCare Companion app.	Daily monitoring of patients consists of telephonic outreach from a registered nurse or allied health professional and a self-monitoring app (MyCare Companion) that allows for patient-entered data. A pool of nurses and clinicians monitor the EMR registry and flag symptoms that are worsening. After a nursing assessment, a patient may then be escalated for additional care (virtual call or referral to ED).	Time to escalation, ED attendance, admission, mortality.

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	Author	Country	Study type/ Publication	Phase	Intervention	SC	Inclusion criteria	Onboarding/ Follow-up	Data	Data recording	Contact/ Follow-up	Outcomes
							disease, HIV/AIDS, and organ transplant.					
13	Lam**	Canada	Feasibility study/ Published article	Pre-admission	Virtual care program	SC	Adult patients who tested positive for COVID-19.	Infection Prevention and Control receives positive test result. Patient contacted via phone to onboard. Follow-up was discontinued after signs of clinical improvement.	**Data for risk assessment:** Clinical and travel history, symptoms, exposure. **Data for monitoring:** changes in symptoms (including temperature).	Online and paper-based: Patients record data on the Ontario Telemedicine Network virtual care platform, but if they refuse, these data were collected by phone.	Stable patients contacted a minimum of once a week, patients who were deemed to require more frequent follow-up were contacted up to twice a day by telephone. Escalation arranged by the service to ED.	Time from swab collection to first assessment, duration of virtual care, ED attendance, admission, ICU admission, mortality.
14	Grutters*	The Netherlands	Description of service/ Published article	Step-down	Home telemonitoring, remote patient monitoring	SC	Hospitalised patients considered appropriate for discharge with remote monitoring.	When patient's clinical condition in hospital improved, they were approached for the home monitoring service.	**Data for risk assessment:** Clinical and travel history, symptoms, exposure **Data for monitoring:** Symptoms, pulse oximeter and temperature readings.	Online: Patient recorded data on an app on a daily basis. Patients were able to post comments on the app.	Data from the app displayed on a real-time basis on a dashboard. Staff also made calls to help with oxygen therapy queries and for follow-ups.	ICU admission, LoS, reassessment at hospital, readmission, mortality, patient experience, costs.
15	Shah*	USA	Observational study (prospective study)/ Published article	Pre-admission	Home pulse oximetry monitoring	SC	Confirmed or suspected COVID-19 presenting in ED.	Patient discharged from ED with confirmed or suspected COVID-19 and were given a pulse oximeter.	**Data for risk assessment:** Demographics, medical history, lab tests **Data for monitoring:**	Paper-based: Patients recorded measurements and communicated these to staff once a day during a phone call.	Patients were called once a day.	Admission, resting pulse oximeter readings, LoS, ICU admission, time to drop, development of acute respiratory distress syndrome, septic shock,

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#	Author	Country	Source	Model	Type	Care	Population	Setup/Inclusion	Data	Monitoring	Escalation	Outcomes
									Patients were followed-up for 7 days.	Symptoms, pulse oximeter and temperature readings.		mortality.
16	Morgan**	USA	Description of the service/ Published article	Pre-admission and step-down	Remote monitoring patients	SC	Confirmed or suspected cases.	Patient could be added to the service after testing positive, during an ED visit, a call or telehealth visit with any clinician, or following discharge from an inpatient admission.	**Data for risk-assessment:** symptoms **Data for monitoring:** symptoms	SMS based: patient received twice-daily message and could reply to messages sent by the clinical team.	Patients were monitored by a nurse as information submitted by patients triggered EHR inbox message.	ED attendance, admission, length of stay, escalation.
17	O'Carroll*	Ireland	Description of the service/ Published article	Step-down	Remote monitoring	SC	Confirmed patients deemed suitable for discharge	Patients who could be discharged from hospital as they did not require supplemental oxygen.	**Data for monitoring:** symptoms, oxygen saturations (pulse oximetry).	Pulse oximeters were connected to an app. The app sent a prompt to patients to record oxygen saturations 4 times a day.	The app triggered an alert and the medical team contacted the patient and gave instructions on next steps.	Readmissions, length of stay, ICU admission

*Used a pulse oximeter
**Did not use pulse oximetry in the main model described in the article but flagged the launching of a companion programme or incorporating pulse oximetry and escalation based on oxygen saturation at a later date.
***Pulse oximetry added three weeks after implementation
SC=secondary care
PC=primary care

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