The use of telemonitoring in managing the COVID pandemic

Title: The use of telemonitoring in managing the COVID pandemic: a pilot implementation study

Abstract

Background: Most people with COVID-19 self-manage at home. However, the condition can deteriorate quickly and some may develop serious hypoxia with relatively few symptoms. Early identification of deterioration allows effective management with oxygen and steroids. Telemonitoring of symptoms and physiological signs may facilitate this.

Objective: To design, implement and evaluate a telemonitoring system for people with COVID-19 self-managing at home considered at significant risk of deterioration

Methods: A multi-disciplinary team developed a telemonitoring protocol using a commercial platform to record symptoms, pulse oximetry and temperature. If symptoms or physiological measures breached targets, patients were alerted asking them to phone an ambulance (red) or for advice (amber). Patients attending COVID assessment centres, considered fit for discharge but at risk of deterioration, were shown how to use a pulse-oximeter and the monitoring system which they were to use twice daily for two weeks. Patients could interact by app, SMS or touch-tone phone. Written guidance on alerts was also provided.

Following consent, patient data on telemonitoring usage and alerts were linked to data on service resource use. Subsequently, patients who had both used and not used the telemonitoring service, including those who had not followed advice to seek help, agreed to brief telephone interviews to explore their views on and how they had interacted with the telemonitoring system. Interviews were recorded and analysed thematically. Professionals involved in the implementation were sent an online questionnaire asking them about their perceptions of the service.

Results: We investigated the first 116 patients who used the service. Of these 71 (61%) submitted data, the remainder chose to self-monitor without electronic support. Of the 71 patients who submitted data, 35 received 151 alerts during their two-week observation. Sixty-seven 'red' alerts were for oxygen saturation (Sa02) levels ≤93% and 15 because they recorded severe breathlessness. Nineteen were admitted to hospital (average stay 3.4 days). Of the 45 who used written guidance alone, eight were admitted to hospital (average stay 5.3 days) and one died.

Some patients who were advised to seek help did not do so, some because parameters improved on re-testing, others because they felt no worse than before. All patients found self-monitoring reassuring. Most professionals who used the system (n=11) found it easy to use and useful. Five professionals considered the system 'very safe', three thought it 'could be safer', and three wished more experience before deciding. Two felt SaO2 trigger thresholds were too high.

Conclusions: Supported self-monitoring of patients with COVID-19 at home is reassuring to patients acceptable to clinicians and can detect important signs of deterioration. Worryingly, some patients, because they felt well, occasionally ignored important signs of deterioration. It is important therefore to emphasise the importance of the early investigation and treatment of asymptomatic hypoxia at the time when patients are initiated and in the warning messages that are sent to patients.

Background

It is well recognised that some patients affected with Coronavirus disease 2019 (COVID-19) who are initially not seriously unwell, will later develop severe disease requiring hospital admission. However, in most countries only the most seriously ill are admitted as hospitals quickly have become over-run [1-3].

It has become clearer that early treatment of people with deteriorating disease is associated with better outcomes [4]. An analysis of early data from Jiangsu province in China suggested that early intervention reduced death rates (<1%) in comparison with Hubei Province (4.3%) where treatment was started later [5]. Likewise in South Korea, analysis of data showed that later presentation was associated with poorer outcomes, and countries such as Singapore which had a policy of early admission to hospital had a very low fatality rate [6,7]. Additionally delayed admission and level of presenting oxygen saturation (SaO2) in English patients has been shown to predict outcome with even relatively small reductions of SaO2 of 95% and below associated with increases in mortality [8].

Early treatment is effective. Most of the lung injury in COVID-19 is due to inflammation [9] and in severely ill patients, the use of oxygen, steroids and novel anti-inflammatories, along with general supportive therapy have been shown to reduce death rate or shorten admissions [10-13].

The elderly and those with underlying medical conditions are at increased risk of deterioration [14] Other groups (healthcare staff, some ethnic minorities, and people with high body mass index) are particularly known to delay presentation which is associated with poorer outcomes [15].

The high death rate in the UK in those admitted too late for treatment to be effective, led to calls for more active monitoring both to detect early deterioration in these at risk groups and to encourage them to seek help [16].

Detecting early deterioration

Detecting deterioration can be challenging. Many patients present with pronounced arterial hypoxaemia yet without proportional signs of respiratory distress or sense of breathlessness. Dyspnoea was reported by only 18.7% of hospitalised patients in one series [17]. However, in some patients with significant lung disease, normal SaO2 can also be initially maintained by hyperventilation. It is important therefore to consider both symptoms of breathlessness and SaO2 to detect deterioration in COVID-19 [18]. Additionally, in some people with chronic lung disease borderline SaO2 is relatively frequent and may be less predictive in COVID-19 than the general population [19].

A recent Delphi exercise based in UK primary care, involving 72 clinicians, set out to develop an early warning score for deterioration in COVID-19 [20]. The authors suggested the following to be valuable in predicting deterioration : fast pulse rate, shortness of breath or respiratory rate, trajectory of breathlessness, pulse oximeter reading (with brief exercise test if appropriate) or symptoms

suggestive of hypoxia, temperature or fever symptoms, duration of symptoms, muscle aches, new confusion, shielded list and known risk factors for poor outcome. They suggested a scoring system, the sensitivity and specificity of which is yet to be assessed.

Many of the physiological parameters above are easily measured by low-cost devices, however it is important that these meet a quality standard (e.g. ISO 80601-2-61:2017 for pulse-oximeters). These are accurate within the range required to detect desaturation requiring hospitalisation. Many wrist-worn oximeters and smartphone based oximeters are generally unreliable [21-23]. Raised respiratory rate, a strong predictor of poor outcomes, is more challenging to measure remotely [24,25], but, recently, pulse-oximeters which can estimate respiratory rate using the photoplethysmography (PPG) waveform and its amplitude variation have become available [26,27].

Some countries have recommended and variably implemented the use of self-monitored pulse-oximetry with daily nurse telephone follow-up in a 'virtual ward' arrangement [28,29]. At times of high community incidence though, when demand on all healthcare can rapidly rise, such intensive follow-up may be infeasible given that most patients will remain relatively well.

Telemonitored supported self-management for COVID-19

An alternative is to support self-management with a telemonitored approach. Patients are requested to regularly record symptoms and physiological parameters and, if these suggest deterioration, automatic alerts to the patient recommend seeking advice or urgent care. The record is available for review by their clinicians. This is expected to facilitate early intervention and hence improve the patient's eventual outcome.

Telemonitoring has been adopted in several locations world-wide. As yet, there are no randomised controlled trials (RCT) of telemonitoring in COVID-19, although two are under way in the USA and Norway and scheduled to report later in 2021 [30,31]. However, several papers describing the early experience with telemonitoring systems in COVID [32,33] and for facilitating early hospital discharge after COVID have been published [34-37]. All made use of pulse oximetry and some also measured temperature and recorded a variety of symptoms. The implementations employed a range of trigger alert levels for SaO2 (from <90% to <95%). The number of alerts varied across the studies, reflecting the trigger level settings and different populations being monitored (some were relatively young with few underlying conditions whereas in one some patients were receiving home oxygen) [38]. Overall telemonitoring was perceived as being helpful in detecting deterioration.

Ideally, telemonitoring systems should work across a range of mobile phones, tablets and computers, and link to health service systems using open standards so that the service obtains timely robust data which are critical to managing workload. Telemonitoring systems that require patients to subscribe using their own smartphones or tablet PCs, could exclude more vulnerable older and poorer people who are less likely to have a smartphone or internet access [39].

There are potential risks to telemonitoring, such as over-reliance on physiological parameters by inexperienced clinicians, poor adherence to self-monitoring, failure to respond to alerts or faulty equipment. Implementations should be within an evaluative framework which examines impact on workload, utility to clinicians, usability, acceptability to patients and equity of access. In particular,

rapid feedback of evaluation findings will be needed to modify and optimise the intervention. Below we describe the design and initial evaluation of a Scottish COVID home-monitoring system.

Scottish COVID home-monitoring system

In Scotland health services are provided free at point of care, paid for from general taxation. Early in the pandemic a COVID-19 clinical pathway was developed to manage patients according to their level of perceived risk (See table 1). Substantial numbers of people, with mild disease at first assessment but potentially at risk of future deterioration, are asked to remain at home and to call back only if symptoms are worsening. However, some may delay or develop low oxygen saturation with few symptoms and as a result be admitted to hospital later than is optimal. Recognising the need for early detection of deterioration in COVID-19 in the late summer of 2020 the Scottish Chief Medical Officer called for systems to detect and manage this.

Table 1: Risk stratification of suspected COVID-19 patients in the UK

Risk stratification in the UK involves multiple layers of decision-making:

1. People who consider themselves to have an immediately life-threatening illness can phone 999 for emergency ambulance, paramedic assessment and admission to hospital.
2. People with less severe symptoms are steered to online advice (e.g. https://111.nhs.uk/covid-19), where a symptom checker directs people to self-management advice if minimal or no symptoms, to call NHS111 if more significant symptoms, and to call an ambulance if life-threatening symptoms.
3. Anyone can ring NHS111 for non-medical telephone advice and, depending on symptoms and their individual circumstances, a proportion are referred for GP telephone consultation or emergency assessment (calling an ambulance to attend the emergency room).
4. GP telephone consultation may lead to advice only, face-to-face community assessment, or emergency assessment. Video consultations may also form part of a wider strategy of remote care for COVID-19 [17].
5. Face-to-face assessment may lead to advice to continue self-care at home, or to admission to hospital.

Developing the monitoring system

Following the formation of an expert group (drawn from Scottish Government clinical advisors, primary and secondary care, the Scottish unscheduled care service (NHS24) and the Scottish Ambulance Service), a clinical protocol, based on current evidence and early international experience of telemonitoring, was developed. This protocol was subsequently approved by national professional groups. The system, based on a commercial platform (Inhealthcare® https://www.inhealthcare.co.uk/), provides twice daily reminders to record symptoms and collect data on pulse oximetry (at rest and post-exercise) and temperature over a 14 day period [40]. (See table 2) Patients can interact with the system by internet, app, SMS or by responding on their telephone keypad to pre-recorded questions.

If responses suggest moderate deterioration, patients receive an automatic message advising them to phone 111 (the UK unscheduled care number) and their call is directed to general practitioners for

initial telephone assessment. If symptoms or readings suggest a severe deterioration requiring possible hospitalization, patients are directed to call 999 (UK emergency number). (See appendix 1)

Table 2: Telemonitoring data collected.

Twice daily for 14 days

- Symptom data:
  - Breathlessness – At rest, or on minimal activity
  - Cough
  - Fever
  - Severe recent onset fatigue
  - Myalgia (triggered advice on self-management only))
- Physiological parameters:
  - Pulse rate, SpO_2 (after 20 minutes seated and, if physically able, after 1 minute walking, or sitting to stand), temperature

Setting triggers for symptom and physiological measurements

Initial alert levels were based on expert clinical judgement and on extrapolation from other respiratory conditions and on national advice [41]. Trigger alerts were set for oxygen saturation, pulse, temperature and for worsening breathlessness and severe fatigue of recent onset (See table 3 for triggers, rationale for these and advice given to clinicians on how to respond to these). It was expected that linkage of telemonitoring data to outcomes (reassessment, admission to hospital, need for respiratory support or ICU, death) would inform subsequent adjustment of alert thresholds. Saturation triggers were in part relative (a sudden fall from a higher level to 95% or 94% triggered an advice call) but a level of 93% or lower triggered an urgent warning. There was considerable debate about the trigger which occurred as a result of a fall to 95% from a higher level as there were concerns that this would create unnecessary workload. In the end concerns, particularly about underdiagnosis of hypoxia in people with pigmented skin, led to the adoption of this trigger. To test post exercise desaturation, patients whose resting saturation was 95% or above were asked to exercise (brisk walk or sit to stand) for one minute (or as long as they could) and remeasure their oxygen saturation. If this fell below 94% it triggered an alert. Because of the difficulties interpreting readings from people who had existing significant respiratory conditions and long-term lower oxygen levels, this group was initially excluded.

A symptom report of myalgia or cough resulted in an automatic suggestion to consider using symptom relieving medicine only and did not trigger an alert.

Table 3: Alert triggers set for the Scottish telemonitoring system and suggested response.

Symptom/ physiological reading recorded by patient	**Advice to patient**	**Rationale**	**Considerations for clinician**
Breathless difficulty speaking	You seem very breathless Phone 999*	Suggests severe illness, but may be anxiety	Normally managed by the Scottish Ambulance Service
Worsening breathless Breathless on minimal exertion	You seem to be getting more breathless please phone 111** for advice	Worsening breathlessness is an early sign of severe COVID.	Speak with patient to confirm decline, does patient sound breathless at rest, are they drinking and eating. If patient has oximeter and saturation is ≥94% after 1 min exercise and otherwise OK consider continuing observation with safety-netting. If patient does not have functioning oximeter consider seeing to measure saturation and assess respiratory rate
Severe tiredness/exhaustion in last 24 hours. ***(only triggers call to 111 if no pulse oximeter available)***	Sudden onset of tiredness can suggest a deterioration in your condition please phone 111 for advice	Severe tiredness is associated with hypoxia	Speak with patient to confirm decline, review oxygen saturation if available, have they become more breathless, are they drinking and eating, is there evidence of secondary infection? Consider reviewing to check oxygen saturation if they do not have a functioning oximeter
Oxygen saturation <94%	Your oxygen level is very low please phone 999	Low oxygen saturation, may require oxygen therapy	Normally managed by the Scottish Ambulance Service
Oxygen saturation 94% or 95% at rest ***(only triggers alert if previously higher than 95%)***	Your oxygen level is a little low please phone 111 for advice	May be important if a falling level particularly if associated with increased breathlessness	Speak to patient to confirm general status, check for increasing breathlessness. If level has fallen from previously high level, particularly in the presence of increased breathlessness, suggests worrying deterioration and therefore consideration of further assessment
Resting pulse rate >100 bpm	Your pulse rate is higher than expected, please repeat after resting and if still over 100 please phone 111 for advice	Resting tachycardia suggestive of serious illness.	Speak to patient to confirm general status, increasing breathlessness, Compare with previous heart rate measures if relatively stable and close to 100 consider observing. If rising, consider worsening COVID, pulmonary embolus or arrythmia (atrial fibrillation is a common complication of COVID-19)
Persistent fever of > 38^{o}C for more than 5 days	Your temperature has been high for 5 days or more please phone 111 for advice,	Raises concerns about potential secondary infection. Increased risk of serious outcome.	Speak to patient to confirm general status, increasing breathlessness, chest pain, coloured spit, symptoms of other infections like UTI. Consider further examination/investigation
One off fever of > 38.5 ^{o}C	Your temperature is higher than expected, please phone 111 for advice.	Raises concerns of severe illness	Speak to patient to confirm general status, increasing breathlessness, chest pain, coloured spit, symptoms of other infections like UTI. Consider further examination/investigation

*999 is UK emergency ambulance number. **111 is for telephone medical advice and triage

Selecting patients for monitoring

Initially in Scotland the system was offered to people attending primary care COVID Assessment Centres in person after a physical examination, and in the remote and rural setting to patients admitted briefly but considered fit for discharge and self-monitoring. However, it was expected that initiation from emergency departments, general practice or remotely, following video assessment, would also be possible. People considered at higher risk of deterioration, (but with symptoms and physiological signs below the threshold for hospital admission) were offered monitoring. Although algorithm-based calculators such as COVID-AGE [42] were considered, the final decision on whom was considered suitable for monitoring was left to the assessing doctors usually based on age, underlying illness, clinical condition, and capacity to manage the system (see figure 1). Patients were given a pulse oximeter and shown how to use it. They were told not to wait for requests for data if they felt they were deteriorating but to phone immediately for advice. It was made clear to patients that the system was based on self-monitoring, that there was no systematic review of alerts and that it was their responsibility to seek help if symptoms or physiological measures suggested this. Patients were also given written guidance on using the device and on what to do should trigger levels be breached and could opt to self-monitor without telemonitored support.

A full description of the system, including information for clinicians and patients, governance and technical information is available online. [43,44]

Initial experience with the system

Two Scottish health boards, one rural and one mixed rural/urban, took part in the pilot implementation. Levels of COVID-19 had begun to fall in the rural area, however, the mixed urban/rural area still had high levels of transmission. The following describes the experience of the first 116 patients.

Methods

Completion of the UKRI/MRC/NHS RHA decision tool (15.4.21) confirmed that this evaluation 'would not be considered research by the NHS' and therefore did not require ethical approval. All patients who took up the offer of telemonitoring gave permission for their data to be used to evaluate and improve the service. Data were extracted from the Inhealthcare system and linked to service resource use by the NHS Board team. The clinical team subsequently obtained verbal consent for a follow-up telephone interview with sample of patients selected on the basis of age, sex, whether or not they had used the system, received alerts, their response to any alerts, and subsequent resource use.

Interviews were carried out by HA, who was not involved in the design or implementation of the system. Caldicott Guardian approval was granted by NHS Highland (15.4.21) for sharing data related to interviewing their patients. This was not required for NHS Lanarkshire as HA is an employee. All interviews were conducted by telephone (see appendix for topic guide), digitally-recorded and analysed thematically.

Professionals involved in the implementation were sent a link to an on-line questionnaire (see appendix) asking them about their perceptions of the safety and utility of the system, ease of onboarding and explaining the system to patients, the professional user interface, the appropriateness of the triggers and suggestions for improvement.

Results

System and resource use data

Of the first 116 patients who were given oximeters and expressed interest in using the system, 56% chose to use SMS, 28% an app, 6% web portal and 5% automated call-back with touch tone phone. (5% missing data). Of those who signed up 71 (61%) submitted some data. The remaining 45 (39%) could choose to self-monitor without telemonitored support. Table 4 shows the demography of the participants.

Table 4. Demography of the participating patients. There were 111 patients from Lanarkshire and 6 from Highland.

Cohort n=116	**Those who submitted readings (n=71)**	**Those who did not submit readings (n=45)**
Sex	40 women, 31 men	20 women, 25 men
Average age *(range)*	51.3 years *(24-94)*	54.0 years *(25-87)*

The alert history and their subsequent service contacts are summarised in table 5. Of the 71 patients who sent data, 35 patients alerted at some point, logging 151 alerts. Of these, 28 patients had 'red' emergency alerts suggesting they call an ambulance and 6 people received only 'amber' advice-only alerts. The same episode could trigger several alerts for different parameters or symptoms. Sixty-seven red alerts were triggered by oxygen saturation levels lower than ≤93% and 15 by responding that they were "unable to speak in sentences because of breathlessness". Table 5 shows how these patients subsequently used health services. There was one death. However, this occurred two days after assessment in a patient who had not used telemonitored support.

Table 5. Alerts issued and subsequent health service use.

Cohort n=116	**Those who submitted readings (n=71)**	**Those who did not submit readings (n=45)**
Total no. amber alerts	69	N/A
Total no. red alerts	82	N/A
No. people who received at least one amber but no red alerts	7 (10%)	N/A
No. people who received at least one red alert	28 (39%)	N/A
No. who phoned 111 (out of hours primary care)	18 (258%)	11 (24%)
No. who contacted COVID assessment centre	8 (11%)	4 (8%)
No. who attended emergency department	19 (27%)	10 (22%)
No. admitted to hospital	19 (27%)	8 (17%)
Average length of hospital stay (days)	3.4	5.3[a]
Deaths		1

[a] *One patient stayed in hospital for 14 days, increasing the average length of stay from 4 to 5.3 days.*
A single episode could generate several alerts and several contacts, for example a patient with breathlessness could also generate alerts for low SaO2, high pulse and temperature. The patient could contact NHS24 be directed to the COVID assessment centre, then on for assessment in the emergency department before admission to hospital. Some were admitted directly to hospital via ambulance while most passed through the emergency department.

There were several instances where patients ignored red alerts to seek advice. Figure two shows the case flow of several such patients, and this is discussed further in the interview analysis.
Patients had been encouraged not to wait for a request for data if they thought their condition was worsening. Eight patients who sent data, but had not received alerts had a total of four ED attendances, four OOH contacts, three COVID-19 assessment centre contacts and four hospital admissions (average length of stay 3 days).

Contact rates and hospital admission rates were similar for people who did and did not use the telemonitoring support.

Patient interviews

Fourteen patients agreed to participate in a brief telephone interview (see table 6 for patient characteristics) to explore their experience of using the system, determine why some had not followed advice to seek help and why others had chosen not to send data. These were conducted between 5 and 8 weeks after signing up for remote monitoring and lasted an average of 6.5 minutes.

Table 6. Characteristics of interviewees.

	Age	Sex	Channel chosen	Alerts	Responded to alert(s)	Hospital admission (length of stay)
1	31	Female	SMS text	2 red, 1 amber	No	No
2	49	Female	App	5 red, 1 amber	No	No
3 [a]	47	Male	SMS text	2 red	No	No
4 [b]	75	Female	SMS text	1 red	No	No
5	66	Male	SMS text	8 red, 4 amber	Yes	Yes (1 day)
6	54	Female	SMS text	1 red, 3 amber	Yes	Yes (< 1 days)
7 [b]	25	Male	SMS text	1 red	Yes	No
8	47	Male	SMS text	7 amber	Yes	No
9	55	Male	App	1 amber	Yes	Yes (<1 day days)
10	36	Female	SMS text	1 amber	Yes	No
11 [b]	92	Female	App	None	N/A	No
12	41	Male	SMS text	No readings[c]	N/A	No
13	70	Male	App	No readings[c]	N/A	No
14	50	Male	SMS text	No readings[c]	N/A	No

[a] *Patient interviewed, but spouse did monitoring*

[b] *Interviewed carer/relative who was responsible for remote monitoring*

[c] *Self monitored but did not submit data*

All 11 people interviewed who had used the remote monitoring system described it as '*easy*' or '*straightforward*'. Interestingly, in four cases the monitoring had been done on behalf of the person with COVID-19, either because the patient was unable to (due to dementia or special needs) or because someone was better able to engage with the technology on their behalf. For this group, being less digitally literate was not necessarily a barrier to remote health monitoring. Although three of the interviewees had not uploaded readings, they had used the pulse oximeter and felt it had been '*a good idea*' or '*a comfort*' to them. All 14 people interviewed said remote monitoring provided reassurance or 'stopped you worrying' and endorsed its use by others in the same position. However, not everyone monitored for the full two weeks, one saying they '*just got scunnered* [fed-up] with it'.

Four interviewees had received alerts from the system but elected not to follow the advice received. Two explained that instead of calling 111 or 999 immediately they had waited 10 minutes, taken their readings again, and found they had gone '*back to normal*'. One added there was '*nothing to panic about*' and the other went on to say, '*I knew I wasn't really needing help*'. This was also the prime motivation for the third person (a former healthcare employee) who did not follow the advice received; '*I know myself because I felt OK'*. Two of those not following the advice felt the healthcare resources should have been left for '*somebody else that does need it'*. The decision not to respond to alerts for the fourth person was made by her niece who was doing the monitoring. She explained that some were triggered by submitting the wrong readings, whilst others were when her aunt was '*really not good*'. The niece was clear that on the night after being assessed, '*she wouldn't have wanted it anyway, so I didn't bother*' and they had agreed she would wait to get better.

Although it was more difficult to make contact with those who had chosen not to submit data, three agree to an interview. They all valued having the pulse oximeter and reported that they had used it, either twice a day, as directed, or more often e.g., '*every couple of hours'*. One was still using it six weeks after being given it, and another had found it so useful they had passed it on to other family members who had tested positive for COVID-19.

In terms of the reasons for not uploading monitoring results to the system, one person had clearly misunderstood that they were supposed to do so. They reported that they were 'meant to tell the doctor' and had not been asked to submit results via a mobile, computer or landline phone. They demonstrated a facility with taking their readings during the interview. The other two who had not submitted results said they had felt too unwell to engage with it. One valued '*having the meter there*' because '*you knew the safe limits and it was a comfort knowing you were within those safe limits*' and the other referred to the trigger levels in the leaflet and said, '*if I got to that level, I'd obviously have to call the emergency services*'.

Many interviewees described how much they appreciated having knowledge of what their monitoring levels should be following their COVID-19 diagnosis. One said it was '*an eye opener'* because '*this disease is going after the respiratory system and that's the one we need to watch*'. Another who was '*not a medical person*' found it interesting '*to understand how things change when you walk about and sit down a wee bit out of breath*'. A third had been keen to engage after hearing news about pulse oximeters '*being able to indicate that people were beginning to become more unwell without feeling it*' and one suffering from fatigue seven weeks later still checked their levels after being active.

Curiously, one interviewee who hadn't responded to their alerts suggested others should behave differently, saying '*I would like to think they would do what it says and respond*'. Another said that the reassurance they got from monitoring meant they '*didn't phone NHS24* [111 the unscheduled care service] *as much as maybe without it* [they] *might have*' and a third felt more generally that it would '*save a lot of people from phoning 111 or 999 when really it wasn't necessary*'.

Professionals' views

Fourteen professionals responded to the on-line survey; six doctors, six nurses, one administrator and one who did not give their role. Three had not used the remote monitoring system, but one of them commented '*it's a great idea'* and explained the only reason they'd not used it was because they had mainly seen children rather than adults. One of those who had not used the system did not consider the system was useful or safe.

Of the 11 professionals who had used COVID-19 remote monitoring, six had found it 'fairly' and five 'very' useful. Five thought it was 'very safe', three that it 'could be safer', two were not sure and one felt it was too soon to say. All who had initiated patients on the system found it very (n=5) or fairly (n=5) easy, and the three who had used the professional user interface thought it was easy. It was suggested this could be visually simpler, and that permission to individualise parameters would be an advantage.

Seven felt the trigger levels were about right, two weren't sure and two said that alerts were triggered too early. One of these explained that the information around the levels may need to be expanded and the other felt that the oxygen saturation level at which calling an ambulance was

recommended was too high for many people (and would result in too many alerts). In the additional comments section, another felt the number of alerts was 'slightly annoying' and a third felt the fact this was self-monitoring should be stressed to patients and relatives.

National Implementation

Implementing new systems in the midst of a pandemic is very challenging. This solution faced challenges at local levels in terms of information governance and IT compatibility issues which took much longer than expected to resolve. Despite being relatively small country, Scotland is divided into fourteen health boards all with their own governance and IT teams across Scotland which were very stretched with many competing priorities. The solution went live as the peak of Scotland's second wave had passed and so some areas did not feel the same pressure to prioritise this solution. At the time of writing four health boards have used the system and further four are preparing to set up the infrastructure to be available in the event of a third wave following ending of restrictions or in the event of a new variant emerging. Other boards wanted to see the result of the pilot before committing to it.

Discussion

In periods where there is high community transmission of COVID-19, health services run the risk of being overwhelmed. It is sensible, therefore, that people with milder illness are managed at home. However, given that some in this group will deteriorate, it is important that deterioration is detected early enough to allow effective hospital treatment. Self-monitoring of symptoms and oxygen saturation provides a means of achieving this.

Some patients are more likely to deteriorate than others and selection is therefore important, particularly where resources are constrained. Those 'higher risk' patients selected for home monitoring in the Scottish supported home monitoring system had a relatively high hospitalisation rate suggesting that the selection process was relatively effective.

In general, those patients that opted to use it found supported self-monitoring easy to undertake. It was designed to be accessible, offering both digital and non-digital means of communication. It was interesting that most people opted to interact with the system by SMS possibly reflecting an older age group. However, marketing research shows that people are highly likely to read and respond to SMS, more so than other media, and an advantage is that it will work with all kinds of mobile phone [45].

Clinicians also found the system relatively simple to initiate and were largely convinced of its benefits. However, 39% of patients offered the system opted to self-monitor without assistance or not to monitor at all. Patients were introduced to the telemonitoring system at a time when they were variably ill (some felt too ill to use it fully) and when clinical staff were under great pressure. However, everyone interviewed endorsed the system and those interviewed who had not submitted readings had self-monitored with pulse oximetry. Although patients were also given written information, possibly an approach the following day by phone from a dedicated member of a monitoring team would have allowed a better explanation of the system and encouraged take-up.

Although the patients in our case study who opted for telemonitoring were very positive about the feeling of reassurance it gave them, we found that some ignored serious automatic warnings of deterioration even after receiving clear instructions to seek help. When patients were questioned why they did not respond to such warnings, some explained that parameters improved on repeating after a few minutes or that they had miskeyed a response. However, worryingly, others stated that as they felt fine they did not feel the need to call, clearly not realising that asymptomatic hypoxia was potentially dangerous. Clinicians, therefore, need to strongly emphasise this danger when on-boarding patients and it should be reinforced by written materials and in the warning messages.

Nonetheless in many cases where deterioration was identified, this appears to have resulted in appropriate assessment either at a local COVID assessment centre, emergency department or a direct hospital admission. Several people contacted support services about alerts which did not result in change of treatment although this was relatively infrequent. Those who had oximeters but were not transmitting data had had a similar number of contacts. We do not know if this group differed in terms of the severity of their illness at presentation. Interviews suggest that the reassurance provided by monitoring may have prevented some contacts which might otherwise have occurred. In other telemonitored respiratory conditions patients have said that such reassurance allowed them to self-manage rather than call for advice.[46] COVID-19 remote monitoring was not designed to alter workload, but the results of the ongoing RCTs will hopefully inform whether or not it has an impact on both outcomes and workload. The patients interviewed all endorsed its usefulness to them, whether or not they uploaded their monitoring readings, and this early evaluation adds to the emerging evidence base [47].

As a result of this pilot, messaging to patients has changed emphasising the need to contact services if saturations are low even if they feel well and likewise, if symptoms raise alerts, to call even if saturations appear normal.

CONCLUSION

Supported self-monitoring of patients with COVID-19 at home is reassuring to patients acceptable to clinicians and can detect important signs of deterioration. Worryingly, some patients, because they felt well, occasionally ignored important signs of deterioration. It is important therefore to emphasise the importance of the early investigation and treatment of asymptomatic hypoxia at the time when patients are initiated and in the warning messages that are sent to patients.

ACKNOWLEDGMENTS

We would like to thank all the patients and clinical staff in NHS Highland and NHS Lanarkshire who took part, and the many professionals who gave up their time to help design and test the telemonitoring system; John Sandbach, Khyber Alam, Dawn Orr and Laura Ryan (NHS24); Jonathan Will (Scottish Ambulance Service); James Docherty (NHS Highland); Daniel Beckett (NHS Forth Valley); Mark Darroch (NHS Greater Glasgow and Clyde); Dan Hull (National Services Scotland),Karen Thomson and Sharon Russell (NHS Lanarkshire) Kev Dhaliwal, Claire Mackintosh and Oliver Koch (NHS Lothian); Alice Carmichael and Jennifer Graham (Scottish government). Collaborators in the TEC TeleCOVID Group included Lionel Tarasenko and Chris Paton (University of Oxford); Morag Hearty, Russel Scott, Joseph McKee, Scott Henderson, Lesley Middlemiss and Margaret Whoriskey

(Scottish Technology Enabled Care); David Anderson (NHS Greater Glasgow and Clyde); Mhairi Hastings (NHS Education Scotland) and Michelle Watts (Scottish Government)

CONFLICT OF INTEREST

BM has a paid consultancy with the Scottish Government to advise on the implementation of remote monitoring. He has also in the last two years provided consultancy services to Pharmatics a company to design an app to manage COPD. All other authors declare no conflicts of interest.

References

1. Zhou F, Yu T, Du R, Fan G, Liu Y, et al Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet. 2020 Mar 28;395(10229):1054-1062. doi: 10.1016/S0140-6736(20)30566-3. Epub 2020 Mar 11. Erratum in: Lancet. 2020 Mar 28;395(10229):1038. Erratum in: Lancet. 2020 Mar 28;395(10229):1038. PMID: 32171076; PMCID: PMC7270627.

2. Boccia S, Ricciardi W, Ioannidis JPA. What Other Countries Can Learn From Italy During the COVID-19 Pandemic. JAMA Intern Med. 2020 Jul 1;180(7):927-928. doi: 10.1001/jamainternmed.2020.1447. PMID: 32259190.

3. Coebergh J. Only reliable data on hospital-acquired covid-19 will give people confidence that hospitals are safe. BMJ https://blogs.bmj.com/bmj/2020/05/20/we-need-reliable-data-on-hospital-acquired-covid-19/ last accessed 21/6/2020

4. Goyal DK, Mansab F, Iqbal A, Bhatti S. Early intervention likely improves mortality in COVID-19 infection. Clin Med (Lond). 2020 May 1;20(3):248–50. doi: 10.7861/clinmed.2020-0214. Epub ahead of print. PMID: 32357975; PMCID: PMC7354047.

5. Sun Q, Qiu H, Huang M, Yang Y. Lower mortality of COVID-19 by early recognition and intervention: experience from Jiangsu Province. Ann Intensive Care. 2020 Mar 18;10(1):33. doi: 10.1186/s13613-020-00650-2. PMID: 32189136; PMCID: PMC7080931

6. Korean Society of Infectious Diseases and Korea Centers for Disease Control and Prevention. Analysis on 54 Mortality Cases of Coronavirus Disease 2019 in the Republic of Korea from January 19 to March 10, 2020. J Korean Med Sci. 2020 Mar 30;35(12):e132. doi: 10.3346/jkms.2020.35.e132. PMID: 32233161; PMCID: PMC7105509.

7. Wong JEL, Leo YS, Tan CC. COVID-19 in Singapore-Current Experience: Critical Global Issues That Require Attention and Action. JAMA. 2020 Apr 7;323(13):1243-1244. doi: 10.1001/jama.2020.2467. PMID: 32077901.

8. Inada-Kim M, Chmiel FP, Boniface MJ, Pocock H, Black JJM, Deakin CD. Validation of home oxygen saturations as a marker of clinical deterioration in patients with suspected COVID-19. medRxiv preprint doi: https://doi.org/10.1101/2020.11.06.20225938

9. Channappanavar R, Perlman S. Pathogenic human coronavirus infections: causes and consequences of cytokine storm and immunopathology. Semin Immunopathol. 2017 Jul;39(5):529-539. doi: 10.1007/s00281-017-0629-x. Epub 2017 May 2. PMID: 28466096; PMCID: PMC7079893.

10. RECOVERY Collaborative Group, Horby P, Lim WS, Emberson JR, Mafham M et al Dexamethasone in Hospitalized Patients with Covid-19. N Engl J Med. 2021 Feb 25;384(8):693-704. doi: 10.1056/NEJMoa2021436. Epub 2020 Jul 17. PMID: 32678530; PMCID: PMC7383595.

11. Dequin PF, Heming N, Meziani F, Plantefève G, Voiriot G et al; CAPE COVID Trial Group and the CRICS-TriGGERSep Network. Effect of Hydrocortisone on 21-Day Mortality or Respiratory Support Among Critically Ill Patients With COVID-19: A Randomized Clinical Trial. JAMA. 2020 Oct 6;324(13):1298-1306. doi: 10.1001/jama.2020.16761. PMID: 32876689; PMCID: PMC7489432.

12. Horby PW, Campbell M, Staplin N, et al. Tocilizumab in patients admitted to hospital with covid-19 (Recovery): preliminary results of a randomised, controlled, open-label, platform trial.Medrxivdoi:10.1101/2021.02.11.21249258 [Preprint]. 2021. www.medrxiv.org/content/10.1101/2021.02.11.21249258v1

13. Ronco C, Reis T, Husain-Syed F. Management of acute kidney injury in patients with COVID-19. Lancet Respir Med. 2020 Jul;8(7):738-742. doi: 10.1016/S2213-2600(20)30229-0. Epub 2020 May 14. PMID: 32416769; PMCID: PMC7255232.

14. Williamson EJ, Walker AJ, Bhaskaran K et al. Factors associated with COVID-19-related death using OpenSAFELY. Nature. 2020 Aug;584(7821):430-436. doi: 10.1038/s41586-020-2521-4. Epub 2020 Jul 8. PMID: 32640463.

15. Alaa A, Qian Z, Rashbass J, Benger J, van der Schaar M. Retrospective cohort study of admission timing and mortality following COVID-19 infection in England. BMJ Open. 2020 Nov 23;10(11):e042712. doi: 10.1136/bmjopen-2020-042712. PMID: 33234660; PMCID: PMC7684820.

16. McKinstry B, Tarassenko L, Paton C Guthrie B et al The place of telemonitoring in covid-19. https://blogs.bmj.com/bmj/2020/06/12/identifying-severe-cases-of-covid-19-in-the-community/

17. Guan WJ, Ni ZY, Hu Y et al. China Medical Treatment Expert Group for Covid-19. Clinical Characteristics of Coronavirus Disease 2019 in China. N Engl J Med. 2020 Apr 30;382(18):1708-1720. doi: 10.1056/NEJMoa2002032. Epub 2020 Feb 28. PMID: 32109013; PMCID: PMC7092819.

18. Dhont S, Derom E, Van Braeckel E, Depuydt P, Lambrecht BN. The pathophysiology of 'happy' hypoxemia in COVID-19. Respir Res. 2020 Jul 28;21(1):198. doi: 10.1186/s12931-020-01462-5. PMID: 32723327; PMCID: PMC7385717.

19. *Dalbak LG, Straand J, Melbye H. Should pulse oximetry be included in GPs' assessment of patients with obstructive lung disease? Scand J Prim Health Care. 2015;33(4):305-10. doi: 10.3109/02813432.2015.1117283. Epub 2015 Dec 11. PMID: 26654760*

20. Greenhalgh T, Thompson P, Weiringa S et al. What items should be included in an early warning score for remote assessment of suspected COVID-19? Qualitative and Delphi study. BMJ Open. 2020 Nov 12;10(11):e042626. doi: 10.1136/bmjopen-2020-042626. PMID: 33184088

21. Lauterbach CJ, Romano PA, Greisler LA, Brindle RA, Ford KR, Kuennen MR. Accuracy and Reliability of Commercial Wrist-Worn Pulse Oximeter During Normobaric Hypoxia Exposure Under Resting Conditions. Res Q Exerc Sport. 2020 Jul 7:1-10. doi: 10.1080/02701367.2020.1759768. Epub ahead of print. PMID: 32633688.

22. Phillips C, Liaqat D, Gabel M,de Lara E. WristO2: Reliable peripheral oxygen saturation readings from wrist-worn pulse oximeters. 2019 arXiv:1906.07545v1

23. Luks AM, Swenson ER. Pulse Oximetry for Monitoring Patients with COVID-19 at Home. Potential Pitfalls and Practical Guidance. Ann Am Thorac Soc. 2020 Sep;17(9):1040-1046. doi: 10.1513/AnnalsATS.202005-418FR. PMID: 32521167

24. Centre for Evidence Based Medicine. Are there any evidence-based ways of assessing dyspnoea (breathlessness) by telephone or video? https://www.cebm.net/covid-19/are-there-any-evidence-based-ways-of-assessing-dyspnoea-breathlessness-by-telephone-or-video/ Last accessed 14/4/20

25. Rubio N, Parker RA, Drost EM, et al. Home monitoring of breathing rate in people with chronic obstructive pulmonary disease: observational study of feasibility, acceptability, and change after exacerbation. Int J Chron Obstruct Pulmon Dis. 2017;12:1221–1231. doi:10.2147/COPD.S120706 PMID: 28458534

26. Charlton PH, Bonnici T, Tarassenko L, Clifton DA, Beale R, Watkinson PJ. An assessment of algorithms to estimate respiratory rate from the electrocardiogram and photoplethysmogram. Physiological measurement 2016, 37(4), 610. doi: 10.1088/0967-3334/37/4/610 PMID: 27027672

27. Masimo. MIghtySat RxFingertip pulse oximeter. https://www.masimo.co.uk/products/monitors/spot-check/mightysatrx/ Last Accessed 03.09.21

28. Greenhalgh T, Knight M, Inda-Kim M, Fulop NJ, Leach J, Vindrola-Padros C. Remote management of covid-19 using home pulse oximetry and virtual ward support. BMJ. 2021 Mar 25;372:n677. doi: 10.1136/bmj.n677. PMID: 33766809.

29. Vindrola-Padros C, Sidhu MS, TGeorghiou T,Sherlaw-Johnson C, Singh KE et al. The implementation of remote home monitoring models during the COVID-19 pandemic in England. EClinicalMedicine, 2021;34: 100799 https://doi.org/10.1016/j.eclinm.2021.100799. Last accessed 5/4/2021

30. Leff J. Use of Remote Monitoring for COVID-19 Patient (RPM) https://clinicaltrials.gov/ct2/show/NCT04425720 Last accessed 5/4/2021

31. Wik L. Sensor based vital signs monitoring of patients with clinical manifestation of Covid-19 disease during home isolation https://clinicaltrials.gov/ct2/show/NCT04335097 5/4/2021

32. Silven AV, Petrus AHJ, Villalobos-Quesada M, Dirikgil E, Oerlemans CR et al. Telemonitoring for Patients With COVID-19: Recommendations for Design and Implementation. J Med Internet Res. 2020 Sep 2;22(9):e20953. doi: 10.2196/20953. PMID: 32833660

33. Annis T, Pleasants S, Hultman G, Lindemann E, Thompson JA, Billecke S, Badlani S, Melton GB. Rapid implementation of a COVID-19 remote patient monitoring program. J Am Med Inform Assoc. 2020 Aug 1;27(8):1326-1330. doi: 10.1093/jamia/ocaa097. PMID: 32392280

34. Gordon WJ, Henderson D, DeSharone A, Fisher HN, Judge J, Levine DM, MacLean L, Sousa D, Su MY, Boxer R. Remote Patient Monitoring Program for Hospital Discharged COVID-19 Patients. Appl Clin Inform. 2020 Oct;11(5):792-801. doi: 10.1055/s-0040-1721039. Epub 2020 Nov 25. PMID: 33241547

35. Morcillo C. Marzal D, Velazquez J, Tomas JF. Remote Monitoring of Patients with COVID-19 after Hospital Discharge with Connected Health Platform: Outcomes and Quality of Life. Journal of Integrative Cardiology Open Access. http://dx.doi.org/10.31487/j.JICOA.2020.05.05. Last accessed 06/04/2021

36. Ford D, Harvey JB, McElligott J, King K, Simpson KN, Valenta S, Warr EH, Walsh T, Debenham E, Teasdale C, Meystre S, Obeid JS, Metts C, Lenert LA. Leveraging health system telehealth and informatics infrastructure to create a continuum of services for COVID-19 screening, testing, and treatment. J Am Med Inform Assoc. 2020 Dec 9;27(12):1871-1877. doi: 10.1093/jamia/ocaa157. PMID: 32602884

37. O'Carroll O, MacCann R, O'Reilly A, Dunican EM, Feeney ER, Ryan S, Cotter A, Mallon PW, Keane MP, Butler MW, McCarthy C. Remote monitoring of oxygen saturation in individuals with COVID-19 pneumonia. Eur Respir J. 2020 Aug 13;56(2):2001492. doi: 10.1183/13993003.01492-2020. PMID: 32616588.

38. Grutters LA, Majoor KI, Mattern ESK, Hardeman JA, van Swol CFP, Vorselaars ADM. Home telemonitoring makes early hospital discharge of COVID-19 patients possible. J Am Med Inform Assoc. 2020 Nov 1;27(11):1825-1827. doi: 10.1093/jamia/ocaa168. PMID: 32667985

39. Office for National Statistics. Exploring the UK's Digital Divide. https://www.ons.gov.uk/peoplepopulationandcommunity/householdcharacteristics/homeinternetandsocialmediausage/articles/exploringtheuksdigitaldivide/2019-03-04. Last Accessed 05/04/21

40. Inhealthcare. Inhealthcare | Digital health and remote patient monitoring technology Last accessed 5/4/2021

41. NHS England. Pulse oximetry to detect early deterioration of patients with COVID-19 in primary and community care settings. Coronavirus » Pulse oximetry to detect early deterioration of patients with COVID-19 in primary and community care settings (england.nhs.uk) *Last accessed 11/08/21*

42. COVID-19 Medical Risk Assessment https://alama.org.uk/covid-19-medical-risk-assessment/

43. NHS Education Scotland. Remote health Monitoring COVID-19. COVID-19 | Turas | Learn (nhs.scot) *Last accessed 11/08/21*

44. TEC Scotland. Remote Health Pathways Resources. Remote Health Pathways Resources | TEC Scotland *Last accessed 11/08/21*

45. Tap into the Marketing Power of SMS. https://www.gartner.com/en/marketing/insights/articles/tap-into-the-marketing-power-of-sms

46. Fairbrother P, Pinnock H, Hanley J et al. Exploring telemonitoring and self-management by patients with chronic obstructive pulmonary disease: a qualitative study embedded in a randomized controlled trial. Patient Educ Couns. 2013 Dec;93(3):403-10. doi: 10.1016/j.pec.2013.04.003. Epub 2013 May 4. PMID: 23647981.

47. Vindrola-Padros C, Sidhu MS, Georghiou T, Sherlaw-Johnson C, Singh KE, Tomini SM, Ellins J, Morris S, Fulop NJ. The implementation of remote home monitoring models during the COVID-19 pandemic in England. EClinicalMedicine. 2021 Apr;34:100799. doi: 10.1016/j.eclinm.2021.100799. Epub 2021 Mar 30. PMID: 33817610