Supplementary File 3

Review of published evidence on remote monitoring for people with multiple long-term conditions

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In this supplementary file, we present the methods and results of a literature review looking at remote monitoring in people with multiple long-term conditions. We provide evidence on the needs and experiences of people with multiple long-term conditions and the effectiveness of remote monitoring in this population. We also reflect on implications of remote monitoring in terms of health inequalities and differential experiences of vulnerable populations, and what can be done to better support remote monitoring for people with multiple long-term conditions.

Methods

We conducted a literature review looking at remote monitoring for people with multiple long-term conditions in order to provide context to the overarching study and understand the existing evidence that addresses our research questions for the study. The specific aims of the literature review were to identify evidence looking at the use and impact of remote monitoring for people with multiple long-term conditions, and to explore the extent to which needs of people with multiple long-term conditions are being met by remote monitoring interventions.

By remote monitoring, we refer to interventions that collect health data on individuals that is then transmitted to a healthcare provider. We exclude interventions focused only on self-care or self-monitoring (e.g. where a healthcare provider is not in receipt of data), or telecare interventions such as remote consultations or virtual visits where treatment is provided without monitoring data.

Search strategy

A search strategy was developed by the study team after reviewing evidence syntheses on similar topics.[1] The search strategy sought to identify literature that has been published on remote monitoring technologies for people with multiple long-term conditions.

As we were primarily interested in remote monitoring in the UK context, we initially included UK-specific terms in the search strategy for both Scopus and PubMed. After reviewing the results of these searches, we determined there would be very few included articles (n=3) using this strategy. Consequently, in our revised search we expanded the Scopus search string by taking out the UK-specific search terms. We did this in Scopus, rather than in PubMed, as Scopus has wider coverage (more than double the number of papers on the database compared to PubMed, and since it allowed for more sophisticated searches at the time the search was conducted, specifically the use of proximity operators. The searches were conducted in Scopus (see Table S3.1) and PubMed (see Table S3.2) on 4 and 5 October 2022, respectively. Both searches targeted English-language papers published from 1 January 2017 onwards. The search process found 1,411 papers in total after de-duplication.

Table S3.1: Scopus search string (run on 4 October 2022, restricted to articles published since 2017)

#	Category	Terms
1	Search	TITLE-ABS-KEY (("remote sensing" OR "remote sensor*" OR (("remote care" OR "remote healthcare" OR "virtual healthcare" OR "remote health care" OR "remote consult*" OR "virtual consult*" OR "remote follow-up" OR "remote followup" OR "remote manag*" OR "remote monitor*" OR "virtual monitor*" OR "remote outpatient" OR "remote surveillance*" OR "virtual visit*")) OR (telemonitor* OR "tele-monitor*" OR emonitor* OR "e-monitor*" OR telerehab* OR "tele-rehab*" OR erehab* OR "e-rehab*" OR telesurveillance* OR tele-surveillance* OR esurveillance* OR e-surveillance OR "mobile care" OR mcare OR m-care OR "mobile health" OR mhealth OR m-health OR "mobile healthcare" OR mhealthcare OR m-healthcare) OR ((internet* W/3 monitor* OR app W/3 monitor* OR apps W/3 monitor* OR smarthome* W/3 monitor* OR "smart home*" W/3 monitor* OR smartphone* W/3 monitor* OR "smart phone*" W/3 monitor* OR "mobile-based" W/3 monitor* OR e-mail* W/3 monitor* OR email* W/3 monitor* OR "electronic mail*" W/3 monitor* OR emedicine W/3 monitor* OR "e-medicine" W/3 monitor* OR technolog* W/3 monitor* OR computer* W/3 monitor* OR digital* W/3 monitor* OR webbased W/3 monitor* OR "web-based" W/3 monitor* OR webdeliver* W/3 monitor* OR "web-deliver*" W/3 monitor* OR online W/3 monitor* OR outpatient* W/3 monitor* OR out-patient* W/3 monitor* OR ambulator* W/3 monitor* OR home W/3 monitor* OR homebased W/3 monitor* OR "home-based" W/3 monitor*))) AND ("Multiple Chronic Conditions" OR comorbid* OR "Co-morbid*" OR multimorbidity OR multi-morbidity OR multipatholog* OR "Multi-patholog*" OR "multiple condition*" OR "Multiple health condition*" OR "Multiple health problems" OR "Multiple medical conditions" OR "Multiple medical problems" OR "Pluripatholog*" OR "Pluri-patholog*" OR polymorbid* OR "Poly-morbid*" OR "multiple illness*" OR "Multiple Chronic Health Conditions" OR "Multiple Chronic Medical Conditions" OR "multiple chronic illness*")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "cp"))

Table S3.2: PubMed search string (run 5 October 2022, restricted to articles published since 2017)

#	Category	Terms
1	Remote monitoring[1]	"remote sensing" OR "remote sensor*" OR ((remote OR virtual) AND (care OR healthcare OR 'health care' OR consult* OR follow-up OR followup OR interven* OR manag* OR monitor* OR outpatient OR surveillance* OR rehab* OR visit*)) OR (telemonitor* OR tele-monitor* OR emonitor* OR e-monitor* OR telerehab* OR tele-rehab* or erehab* OR e-rehab* OR telesurveillance* OR tele-surveillance* OR esurveillance* OR e-surveillance OR mobile care OR mcare OR m-care OR mobile health OR mhealth OR m-health OR mobile healthcare OR mhealthcare OR m-healthcare) OR ((internet* or app or apps or smarthome* or smart home* or smartphone* or smart phone* or mobile-based or e-mail* or email* or electronic mail* or emedicine or e-medicine or technolog* or computer* or digital* or webbased or web-based or webdeliver* or web-deliver* or online OR outpatient* OR out-patient* OR ambulator* OR home OR homebased OR home-based) AND (manag* or monitor*))
2	Multiple health conditions	Multimorbidity[MeSH Terms] OR "Multiple Chronic Conditions"[Title/Abstract] OR "comorbid*"[Title/Abstract] OR "co morbid*"[Title/Abstract] OR "Multimorbidity"[Title/Abstract] OR "Multi-morbidity"[Title/Abstract] OR "multipatholog*"[Title/Abstract] OR "multi patholog*"[Title/Abstract] OR "multiple condition*"[Title/Abstract] OR "multiple health condition*"[Title/Abstract] OR "Multiple health problems"[Title/Abstract] OR "Multiple medical conditions"[Title/Abstract] OR "Multiple medical problems"[Title/Abstract] OR "pluripatholog*"[Title/Abstract] OR "pluri patholog*"[Title/Abstract] OR "polymorbid*"[Title/Abstract] OR "poly morbid*"[Title/Abstract] OR "multiple illness*"[Title/Abstract] OR "Multiple Chronic Health Conditions"[Title/Abstract] OR "Multiple Chronic Medical Conditions"[Title/Abstract] OR "multiple chronic illness*"[Title/Abstract]
3	Included countries	("united kingdom"[Title/Abstract] OR "UK"[Title/Abstract] OR "great britain"[Title/Abstract] OR "England"[Title/Abstract] OR "English"[Title/Abstract] OR "Scotland"[Title/Abstract] OR "Scottish"[Title/Abstract] OR "Wales"[Title/Abstract] OR "Welsh"[Title/Abstract] OR "northern ireland"[Title/Abstract] OR "northern irish"[Title/Abstract] OR ("united kingdom"[Affiliation] OR "UK"[Affiliation] OR "great britain"[Affiliation] OR "England"[Affiliation] OR "English"[Affiliation] OR "Scotland"[Affiliation] OR "Scottish"[Affiliation] OR "Wales"[Affiliation] OR "Welsh"[Affiliation] OR "northern ireland"[Affiliation] OR "northern irish"[Affiliation]) OR ("NHS"[Title/Abstract] OR "national health service"[Title/Abstract])) NOT ("new south wales"[Title/Abstract] OR "new England"[Title/Abstract] OR "new south wales"[Affiliation] OR "new England"[Affiliation])
4	Language	English
	Search	1 (title/abstract) AND 2 (title/abstract) AND 3 AND 4

[1] Adapted from: Nagase, F.I., Stafinski, T., Avdagovska, M. *et al.* Effectiveness of remote home monitoring for patients with Chronic Obstructive Pulmonary Disease (COPD): systematic review. *BMC Health Serv Res* **22**, 646 (2022). https://doi.org/10.1186/s12913-022-07938-y

Screening

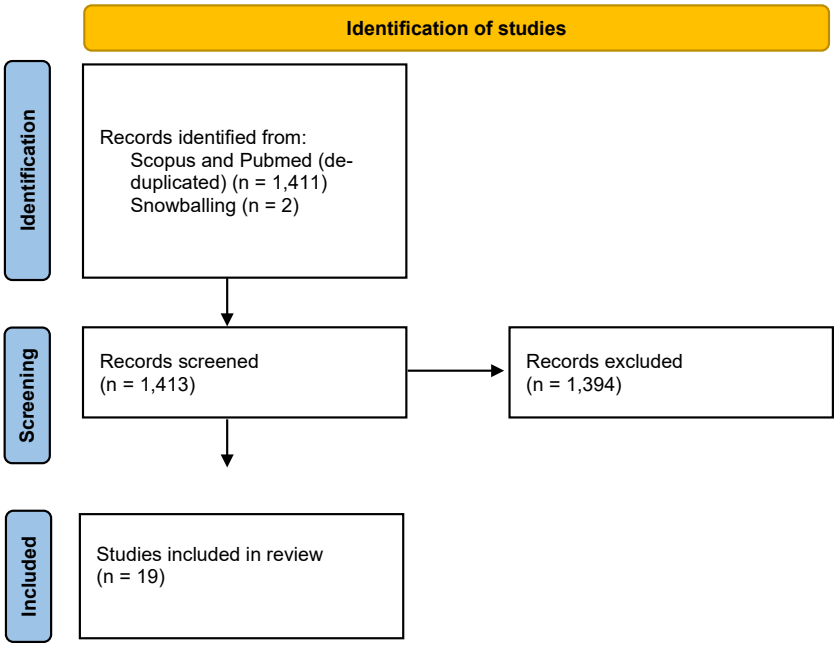
During screening, inclusion and exclusion criteria (see Table S3.3) were applied to the results of the literature search to identify relevant articles. First, a pilot screening was conducted where 30 articles were dual-screened for eligibility based on title/abstract in line with the inclusion and exclusion criteria. The inclusion and exclusion criteria were then further refined for clarity (Table 3), after which a single reviewer screened the remaining articles (title and abstract).

Table 3.3: Inclusion/exclusion criteria

Criteria	Include	Exclude
Topic relevance	Remote monitoring for individuals/patients with two or more LTCs	No reference to remote monitoring and not related to individuals with two more LTCs (i.e. zero or one LTC only)
Scale and spread of intervention	At all scales and geographic levels from individual site to national coverage	None
Article type	Articles with an empirical component Review articles	Theoretical, editorial and commentary articles or letters Trial registrations and study protocols Prevalence studies Case reports Books Errata
Country	UK, EEA countries, Switzerland, Australia, Canada, New Zealand, USA	All other countries
Year of publication	2017 onwards	2016 or earlier
Language	English	Languages other than English
Availability	Full text availability	Title and/or abstract only

A total of 17 papers met the inclusion criteria at screening, with a further two identified via snowballing in the citations of included papers during the extraction stage, resulting in a total of 19 papers. Of these, 17 were primary studies while two were reviews. For a PRISMA flow diagram for our literature review, see Figure S3.1 below.[2]

Figure S3.1: PRISMA flow diagram



Extraction, analysis and synthesis

These 19 papers were then extracted by a single reviewer using a template (in Microsoft Excel) based on the overarching research questions for the study and the aims of the literature review. Each article was also quality assessed. For primary studies the reviewer scored (out of 3) the quality of the evidence source, the clarity of the aims, the clarity of the methods, and the overall quality and comprehensiveness of the study. For reviews, the reviewer scored the inclusion and exclusion criteria, search strategy, quality assessment of included studies, the sufficiency of detail reported for individual included studies and synthesis. Any conflicts of interest were also noted by the reviewer.

Once the extraction of these articles was completed, the extraction template was reviewed to identify main themes. These themes were then discussed during an analysis workshop with the wider study team. After this meeting, the results of the literature review were further analysed to understand the strength of the evidence for each theme, along with the degree of consensus for each finding. Findings were then synthesised. The findings are reported in the following pages.

Findings

This review included 19 studies: 17 primary studies and two reviews of the literature. For a summary of the included studies, please see Table S3.4 at the end of this supplementary file. The findings from the literature are presented below, organised by the following themes in line with our research questions:

- Needs of people with multiple long-term conditions
- The degree to which the needs of people with multiple long-term conditions are considered in remote monitoring interventions
- User experience
- Effectiveness:

    - Self-management and empowerment
    - Mental health and wellbeing
    - Quality of life
    - Physical health and health outcomes
    - Healthcare utilisation
    - Effect on healthcare providers and the healthcare system
- Cost-effectiveness
- Health inequalities and vulnerable groups
- Supporting better remote monitoring for people with MLTCs.

Needs of people with multiple long-term conditions (MLTCs)

The studies included in this review focused on effectiveness and feasibility or use/experience of remote monitoring interventions and did not necessarily collect evidence on the needs of people in multiple long-term conditions. However, many articles discussed the needs of people with multiple long-term conditions in terms of rationales for developing, implementing and evaluating interventions.

Enabling more self-management, not least for people with multiple long-term conditions, has been a focus within the NHS.[4] People with multiple long-term conditions often have complex care needs that require a lot of resources to address. In describing the rationale for remote monitoring interventions, many studies in the literature we reviewed described the goal of helping individuals manage conditions by helping them to: learn about, and become more aware of, their health; adjust their lifestyle or behaviours; and set goals and monitor progression.[5-8] Several studies also described the need for more patient training and education about long-term conditions, particularly for newly diagnosed patients (e.g. risk assessment for conditions such as epilepsy).[5, 9] Many of the included studies cited increased self-management as a factor contributing to the development of remote monitoring interventions, [5, 10-13] and discussed the potential of remote monitoring to lower costs and reduce the strain on the healthcare system resulting from people living with multiple long-term conditions.[14-16]

People with multiple long-term conditions may require more integration of care[15] given the multiple services they are likely to interact with. A lack of integration can create challenges such as the potential for conflicting advice from different healthcare professionals, issues prioritising healthcare needs (particularly in relation to conditions for which a person is currently not experiencing acute symptoms), and increased burden in reporting symptoms and measures to healthcare providers.[8, 9] One study also discussed people with multiple long-term conditions struggling with issues related to polypharmacy, such as medication adherence and adverse side effects.[9]

Some people have needs specific to certain conditions that can make it difficult to manage other conditions. For example, people with certain conditions may face difficulties with memory or organisation (e.g. for people with cognitive impairment), periods of sudden deterioration or mobility issues (e.g. for people with multiple sclerosis).[6] People with multiple long-term conditions often face high levels of burden in managing conditions and may rely on family members and informal carers. As such, it is important for remote monitoring to be integrated into daily routines and existing service pathways[15] and to take into account the role of informal carers.[12]

Studies also mentioned needs of people with multiple long-term conditions that also apply to the general population, regardless of whether they have multiple long-term conditions. For example, several studies also mentioned the importance of maintaining a level of human interaction and face-

to-face contact[6, 7] despite remote monitoring interventions, and the challenges that certain populations face, such as isolation and service gaps in rural settings.[17] One article made reference to how COVID-19 had increased the need for telehealth programmes, including remote monitoring interventions to help people manage conditions without needing to go into hospitals or other healthcare settings.[18] This points to the impact that the pandemic may have had on the need for remote monitoring interventions, both for people with multiple long-term conditions and for the wider population.

The degree to which the needs of people with multiple long-term conditions are considered in remote monitoring interventions

The included studies did not primarily focus on the design process for interventions, and the interventions described vary in terms of the degree to which they were specifically made for people with multiple long-term conditions. However, several studies described steps that were taken to meet the needs of people with multiple long-term conditions and include them and their carers in the design process. For example, Doyle et al. (2021)[8] describe a process of consulting with patients, clinicians, and other stakeholders such as experts and academics to design bespoke features within a remote monitoring intervention that would cater specifically to people with multiple long-term conditions. Through this process, the authors found that patients may be prone to focusing on one condition at the expense of others. This led the researchers to implement a 'flower' user interface to provide unobtrusive prompts for conditions that were not being monitored.[8] A couple of studies also discussed the need to include a patient's entire care network when designing remote monitoring interventions, and providing an option to share data with family members or informal carers.[8, 12]

Several studies emphasised the need for greater patient and carer engagement in the design and development of apps and digital healthcare interventions,[6, 9, 10, 15] which can help ensure that technologies meet user needs. Consulting with patients can also be informative in designing interventions that are easy to use, and that can be integrated into existing routines and healthcare pathways. Additionally, consulting with healthcare providers and patients can support the collection of data that provides enough context to support decision making and action,[19] so that remote monitoring can improve care.

User experience

Participants in most studies reported being satisfied with remote monitoring services, finding them easy to use or acceptable.[5, 6, 8, 10, 11, 14, 20, 21] For example, participants in a trial of an app-based platform to help the self-management of multimorbidities reported that it was usable and low burden, despite submitting an average of 2-3 health readings per day for a year.[8] Several studies also cited high rates of retention, adherence and patient engagement.[5, 6, 8, 11] For example, a study looking at the engagement of older adults with multiple long-term conditions in Belgium and Ireland with remote monitoring (data collected through sensors, a smart watch and a tablet-based app) found high engagement, with over 80% of participants using the technology for at least 200 days, at an average rate of 3-4 submissions of data per week.[6] However, as one study pointed out, many of the views reported in the literature come from people who had agreed to participate in the study and did not drop out,[20] and as such this high level of satisfaction and engagement may be at least partially attributable to selection bias.

Despite overall positive experiences of using remote monitoring technologies, some studies cited issues with user friendliness of technologies[12,15] and technical issues with devices and connectivity.[8, 12, 13, 15] Two of these attribute low retention rates to technology-related challenges.[13, 15] For example, one study looking at the experience of patients with chronic obstructive pulmonary disease and

comorbidities who were using remote monitoring in the form of body worn sensor vests, found that there were issues with sensors not working on people with larger waists or more body hair, which caused issues with reliability of measurements and with compliance.[13] Another study, on the acceptance of telemonitoring by older people with multiple long-term conditions, found that participants reported struggling to provide regular measurements at fixed time intervals, and that the process of submitting readings left them with a feeling that their daily routines were restricted.[15]

Effectiveness

The studies included in this review collected a range of data on the effectiveness of remote monitoring technologies. Most studies collected self-reported data (e.g. from surveys or interviews), such as information on perceived helpfulness in managing health, and data on symptoms, mental health and health-related quality of life. Some studies also measured medical adherence, hospital admissions and healthcare utilisation, or biometric and health outcomes such as blood pressure, glucose, weight and mortality, using data collected by remote monitoring technologies or healthcare data.

The papers reviewed included several large randomised controlled trials that provide strong evidence around the effectiveness of remote monitoring technologies for people with multiple long-term conditions. However, some studies were conducted with small sample sizes and/or used convenience samples.

It is difficult to draw meaningful conclusions about the effectiveness of remote monitoring for people with multiple long-term conditions in general, due to the wide variation in the types of interventions and in study designs. Overall, there is some modest evidence to support that remote monitoring can support self-management, mental health and wellbeing and quality of life in people with MLTCs, although evidence is mixed. Evidence that remote monitoring improves physical health and healthcare utilisation is weaker, although qualitative evidence points to potential benefits of remote monitoring for the healthcare system and for healthcare providers in terms of resource use and workload. These impacts are each discussed in turn below.

Self-management and empowerment

Qualitative evidence supports that some remote monitoring interventions can be helpful in empowering patients to manage their conditions themselves with input from and contact with healthcare providers.[8, 14] For example, participants in the ProACT trial reported that submitting readings to a self-monitoring platform positively impacted their sense of how their actions affect their health and their confidence in not going to a doctor, and they reported taking actions based on the insights the platform gave them.[8] Also, participants in one study with heart failure, uncontrolled hypertension and diabetes reported that a remote monitoring intervention that collected data via a phone-based app and Bluetooth-enabled weighing scales, blood pressure and blood glucose monitors, made it easier to take readings and provided users with more oversight of their condition.[14] However, despite this positive finding regarding patient empowerment, this study did not find evidence that the interventions had an impact on quality of life, mental health or physical health,[14] which suggests that there may be user benefits even where clinical measures do not change as a result of remote monitoring interventions for people with multiple long-term conditions.

Mental health and wellbeing

Some studies found that remote monitoring interventions can be associated with improved mental health and wellbeing.[11,15,18] Kroenke et al. (2019)[11] compared an automated self-management intervention where participants completed a symptom survey by phone or online periodically, with a comprehensive symptom management intervention consisting of the same intervention combined

with a nurse-physician collaborative care team. The comparison found that both interventions lowered pain and improved mood symptoms in patients with chronic musculoskeletal pain, with larger effects in the comprehensive symptom management group, which had more intense contact with healthcare providers.[11] A study of a telemonitoring app for older adults that alerted case managers when parameters exceeded certain values found significant improvements in mental health, although the study had only moderate retention rates, with 34.5% of participants dropping out of the study.[15] A randomised controlled trial of a self-monitoring intervention with an alert algorithm also found that some measures of self-management and social support improved as a result of the intervention.[18]

However, another study found no impact on mental health.[14] A randomised controlled trial of telemonitoring also found no evidence of impact on anxiety, depression or self-efficacy in people with multiple long-term conditions.[14]

Although the majority of studies found only minor negative impacts of remote monitoring interventions, such as frustration or annoyance with the technology, one study also identified a possible harm to wellbeing in that patients who measure parameters that they are unable to understand or interpret may have negative experiences, increased uncertainty and worry.[12]

Quality of life

There is a small amount of evidence showing that remote monitoring technologies can improve quality of life in people with multiple long-term conditions.[20] Hernandez-Quiles et al. (2021)[20] conducted a randomised multi-centre clinical trial of a synchronous home monitoring intervention. Patients were provided with devices and then were asked to submit data on blood pressure, heart rate, oxygen saturation, weight and blood glucose that a healthcare team would review. The study found that the intervention progressively improved health-related quality of life in patients with advanced heart and lung failure, with significant differences in the experience of pain/discomfort and anxiety/depression compared to patients who received usual care.[20] The authors stated that these results were likely due to the interventions promoting feelings of empowerment and protection.[20]

However, other studies found no impact on quality of life.[10, 16] For example, Walker et al. (2018)[16] evaluated a remote monitoring intervention utilising the forced oscillation technique (which measures mechanical properties of lungs during breathing) in older patients with chronic obstructive pulmonary disease and co-morbidities, and found no impact on quality of life.[16] Breckner et al. (2022)[10] also found that a remote monitoring Health intervention for people with chronic diseases had no effects on health-related quality of life or patient activation, although the study had low participation (n=27).[10]

Physical health and health outcomes

Based on the evidence found in this review, the majority of studies do not support that remote monitoring is effective in improving physical health.[10, 11, 14, 15, 18, 19] However, there is weak evidence of some impacts for certain populations.

Ware et al. (2022)[14] conducted a randomised control trial evaluating the impact of a telemonitoring system that collected data via a phone-based app and Bluetooth-enabled scales, blood pressure and blood glucose monitors, and found no evidence that it improved physical health status. Although those with heart failure in this study reported that they benefited from self-care guidance, patients and healthcare providers reported that they did not think the intervention improved clinical management of multiple long-term conditionss.[14] Kroenke et al. (2019)[11] also found that a self-

management intervention where participants completed a symptom survey lowered pain symptoms in patients with chronic musculoskeletal pain, and that effects were stronger when this intervention was combined with a comprehensive symptom management programme from a collaborative care team.[11]

One study noted that the impact on physical health of remote monitoring on health outcomes may be limited by the need for additional context to understand some types of data. A study by Fritz on smart-home detection of health events noted that while the data itself was accurately collected from the sensors, those data would not allow for timely intervention in some acute health events such as strokes. This is because some data (e.g. on changes in daily routine or toilet use) can be attributed to a range of different causes, and understanding the data requires additional contextual information.[19] Similarly, healthcare providers in another study reported that they did not think remote monitoring provided data that could be meaningfully interpreted.[14] One study also attributed the lack of impact to a lack of adherence to the intervention, a lack of integrated care and difficulties fitting remote technologies into daily routines.[15]

Despite this, some studies found positive results in terms of physical health.[9, 17] For example, one study found that the use of a telemonitoring system for rural patients of low socioeconomic status was associated with significant reductions in systolic and diastolic blood pressure, weight and Body Mass Index after 12 weeks,[17] although it was conducted with a small sample size (n=30). Another study found qualitative evidence that experts, healthcare providers and patients think that remote monitoring can be beneficial for patients with epilepsy, multiple sclerosis and depression, particularly in identifying early signals of seizures, flare-ups and depression.[9] Other studies that found positive outcomes in terms of health impacts (also with small sample sizes) were found to be of low quality[21] or did not find evidence that was robust.[5]

Healthcare utilisation

Most of the included studies that addressed healthcare utilisation found that remote monitoring had no impact on healthcare utilisation in people with multiple long-term conditions.[14, 16, 18]

Walker et al.'s multi-centre randomised controlled trial of remote monitoring for patients with chronic obstructive pulmonary disease and comorbidities found no change in time to first hospitalisation compared to usual care (although exploratory analysis for this study found that remote monitoring was associated with fewer repeat hospitalisations).[16] Ware et al. (2022)[14] conducted a randomised control trial evaluating the impact of a telemonitoring system that collected data via a phone-based app and Bluetooth-enabled scales, blood pressure and blood glucose monitors, and found no evidence that it self-reported healthcare use.[14] A randomised controlled trial of a self-monitoring intervention with an alert algorithm to notify a nurse if parameters were over certain thresholds also found no evidence that it resulted in fewer hospitalisations or in-hospital days.[18]

Despite this, one study found positive results in terms of physical health and healthcare utilisation.[9, 17, 20] For example, Hernandez-Quiles et al. (2021)[20] found that real-time monitoring and a rapid-response call-centre was associated with a decrease in hospital and emergency department admissions compared to self-checks on pen and paper and normal integrated care.[20]

Effect on healthcare providers and the healthcare system

Although most studies focused on impacts on the service user, some collected data about impacts on healthcare providers and the healthcare system. One study found that data from remote monitoring can help healthcare providers to prioritise between patients (e.g. based on reported

symptoms and data from remote monitoring),[6] which can be helpful to the care of people with multiple long-term conditions. However, there may be challenges with high volumes of data that can create additional workloads for staff that analyse, interpret and use that data.[6]

Three studies also found that remote monitoring can contribute to better and more efficient communication with patients, for example by saving time in asking patients for information about their symptoms and measures.[6, 7,10]

Cost-effectiveness

Few of the studies we reviewed reported cost or resource use or the cost-effectiveness of remote monitoring interventions. But those that did suggest that interventions can be cost-effective or cost saving. Hernandez-Quiles et al. (2021)[20] found that home monitoring for patients with advanced heart and lung failure was cost-effective, with telecare costs at €4,372 per patient and usual care costs at €8,180 resulting in an incremental cost of €1,233 per quality-adjusted life year (QALY).[20] Similarly, Walker et al. (2018) estimated that patients with multiple long-term conditions receiving remote monitoring for chronic obstructive pulmonary disease had 27% lower healthcare costs compared to people receiving usual care, with an average saving of €1,712 per year per patient (not taking into account the price of equipment and technical support).[16] This was mostly attributable to a reduction in duration and frequency of hospitalisations, although the physical health measures collected in this study were not found to change due to the remote monitoring intervention.[16]

A systematic review of costs of remote monitoring for elderly people with chronic conditions reported that the cost of interventions ranged from $275 to $7,963 per patient per year but that these costs were unreliably reported (meaning that studies did not always report costs in the same way, with varying degrees of granularity and comprehensiveness in which costs were reported).[22] It included studies that were primarily from the USA and Canada, although it included other countries as well (UK, Netherlands, New Zealand, Italy) – since healthcare costs are higher in the USA, this may have influenced the cost range reported in the review. This review included studies published since 2004, since when the costs and nature of technologies has changed. The review did not discuss cost-effectiveness.

Health inequalities and vulnerable groups

Several of the included studies mentioned issues around remote monitoring for people with multiple long-term conditions and health inequalities. Primarily, these focused on inequalities in access to digital technologies and digital capabilities by age, geography, education or socioeconomic status.[6, 7, 10, 12] People with certain vulnerabilities or with particular health conditions may also face additional challenges in accessing and using technology. For example, a qualitative study of older adults with mild cognitive impairment found that although individuals report benefits such as increased feelings of security and independence from telemonitoring, they reported wanting more educational material (including around technical issues and connectivity of devices) and more consideration of their specific needs (for example, around forgetfulness).[12] The authors of this study reflected that this population may be prone to increased worry or anxiety when facing technical issues with technology or connectivity,[12] pointing to the potential for negative impacts from remote monitoring being unevenly spread in the population.

Other included studies focused on vulnerable populations that may face health inequalities. One study in the USA was conducted within a rural setting with participants who were mostly low income and under- or uninsured.[17] Other studies focused on other underserved communities in the USA[5] and Canada.[18]

Looking across the studies included in this review, there are also relevant observations related to health inequalities and vulnerable populations, which were not necessarily stated in the studies but stem from the reviewers. Several studies excluded people without smart phones, computers or internet access,[10, 18, 21] which speaks to the potential for remote monitoring to exclude certain populations that may already face issues around health inequalities. This represents a wider issue around telemonitoring and limits the degree to which telemonitoring can close health equality gaps where vulnerable populations lack key facilitators of remote monitoring such as internet access. There are also selection biases in some studies, in that the people who participated in prospective studies had already agreed to use technology,[20] and so may be expected to have more favourable views of technology than the general population of people with multiple long-term conditions.

Supporting better remote monitoring for people with multiple long-term conditions

The evidence found in the literature review supports that remote monitoring can improve wellbeing, mental health and quality of life (and in some cases, physical health and healthcare utilisation), and that it can increase feelings of empowerment and confidence in managing multiple long-term conditions. As such, it is important to understand what makes remote monitoring more effective in supporting positive outcomes.

Overall, there is evidence that more input from healthcare providers in remote monitoring is beneficial to user experience and increases the effectiveness of interventions.[6, 7, 11, 14, 17] Our review only included studies that had some form of involvement from healthcare providers and so we did not include interventions that were entirely focused on self-monitoring. Active engagement between healthcare providers and the patients being monitored remotely is important to address patient concerns that remote monitoring contributes to a lack of human interaction within the healthcare system. For example, many of the interventions described included regular engagement between patients and healthcare providers, which provided both clinical oversight and person-to-person contact.[6, 7, 11, 14, 17] There was also technical support that was available to service users in the interventions that were the focus of many studies,[6, 8] which was particularly important for people with fewer digital skills and capabilities.

The degree of clinical input influences the cost-effectiveness of remote monitoring interventions and the degree to which they free up resources in the healthcare system.[23] Given the pressures facing the NHS and the focus on self-management, some degree of self-management can be useful in remote monitoring interventions, even where there is clinical input, for example by allowing users to set their own goals and monitor progress.[8] Kroenke et al. (2019)[11] suggest a step-wise approach to interventions, in which a more resource-intensive intervention can be deployed if self-management is not producing the desired outcomes,[11] which can increase the cost-effectiveness of the intervention for the overall population. Interventions can also be designed to alleviate rather than add to the existing burden of healthcare.[12,17] For example, remote monitoring interventions that include preventative health measures that help individuals proactively manage their health (rather than technologies that are focused only on passively monitoring, recognising deterioration or responding to acute emergencies) can help patients and at the same time decrease pressure on the healthcare system.[17]

The lack of integration of services can act as a barrier to effective remote monitoring for people with multiple long-term conditions,[15] as that effectiveness in part depends on the ability to coordinate care across different providers and services.[14] For example, one study reported that a lack of integration and a lack of shared technology systems made it infeasible to offer monitoring for multiple long-term conditions at the same time; instead the intervention had to measure each

condition separately.[14] This suggests the need to ensure that remote monitoring interventions for people with multiple long-term conditions are supported by (and in support of) integrated services, and that there is infrastructure for integrated care (e.g. shared data platforms) that allows for remote monitoring data to be accessed and used by providers across the healthcare system.

Although our review did not focus on the development process of remote monitoring interventions, there is some information relevant to gathering feedback from people with multiple long-term conditions, their carers and healthcare providers. Craven et al. (2020), in their qualitative study to inform the development of a remote measurement technology, utilised a method they developed called 'universal points of care' as a way to elicit and analyse care pathways using scenarios. This method includes asking patients and clinicians how they would go about sharing data, detecting relapses, communicating and selecting treatments to identify requirements of remote measuring technologies. By looking at requirements across different conditions, remote monitoring interventions for multiple long-term conditions can be designed to meet the needs of this population.[9]

Summary of review findings

Box S3.1 provides a summary of findings from the literature review.

Box S3.4: Summary of findings from the literature review

- People with multiple long-term conditions can face burdens related to managing their health, including issues related to a lack of integration in care, difficulty prioritising between multiple health needs, and symptoms from one condition making it challenging to manage others. The complex health needs of people with multiple long-term conditions can be a burden on the healthcare system, and helping people with multiple long-term conditions to self-manage their health has been a focus within the NHS.

- Evidence from the published literature indicates that remote monitoring can be helpful for people with multiple long-term conditions in feeling empowered and confident in managing their conditions, and can help ease some of the burden of reporting symptoms or measurements to healthcare providers.

- There is some evidence to suggest that remote monitoring can improve quality of life, mental health and wellbeing in people with multiple long-term conditions. However, evidence is mixed. The majority of studies looking at the impact of remote monitoring on physical health, healthcare utilisation and health outcomes in people with multiple long-term conditions have not found evidence of impact.

- There is some evidence to suggest that remote monitoring technologies can be helpful in saving resources within the healthcare system. However, more evidence is needed to understand the cost effectiveness of different remote monitoring interventions.

- Some groups of people with multiple long-term conditions may need additional support in using remote monitoring, such as older people and people with cognitive impairment. Remote monitoring technologies often require computer, smart phone and/or internet access, which can contribute to health inequalities among people who are digitally excluded.

- There are several ways the remote monitoring interventions for people with multiple long-term conditions may be improved. There should be careful consideration of how much clinical input is required for remote monitoring, along with consultation processes whereby patients and their carers are considered in the design of interventions. Improvements to integration of care would also improve how remote monitoring can be used for people with multiple long-term conditions.

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Table S3.4: Characteristics of included studies

Citation	Study type	Geography	Study population and sample size (or included articles for reviews)	Conditions that intervention addresses	Intervention	Outcome measures
[10] Breckner A, Litke N, Göbl L, Wiezorreck L, Miksch A, Szecsenyi J, et al. Effects and Processes of an mHealth Intervention for the Management of Chronic Diseases: Prospective Observational Study. JMIR Form Res. 2022;6(8):e34786-e.	Prospective observational study	Germany	Patients enrolled in PraCMan case management program aged 18 and above; 18 patients and 21 primary care workers completed follow-up survey	Type 2 diabetes, COPD, high blood pressure and heart failure	Daily completion of symptoms (mental health) and vitals (blood pressure, weight, blood sugar) tracking by patient, warning system and instructions if symptom or value exceeded specified threshold	Health related quality of life (SF-12) and patient activation (PAM)
[6] Chacornac M, Faoro A, Texereau J, Billoet C, Hominal S. Performance of an eHealth (NOMHAD) System Comprising Telemonitoring, Telenotification, and Telecoaching for Patients With Multimorbidity: Proof-of-Concept Study. JMIR Form Res. 2022;6(3):e32205-e.	Prospective observational study	France	Patients with at least two of chronic heart failure (CHF), chronic obstructive pulmonary disorder (COPD) and diabetes, and at least one hospitalisation for CHF or COPD in year prior to study; 23 patients in study	Chronic heart failure, COPD, diabetes	Monitoring of vitals via Bluetooth devices (blood pressure, weight, etc) and symptom tracking by patient with risk indicators based on symptoms; structured telecoaching and educational support from call centre nurses	Sensitivity and specificity of risk indicators produced by software; questionnaires for patients, nurses, and physicians on ease of use, usefulness, and satisfaction with the system
[23] Clarkson P, Stephenson A, Grimmett C, Cook K, Clark C, Muckelt PE, et al. Digital tools to support the maintenance of physical activity in people with long term conditions: A scoping review. Digit Health. 2022;8:20552076221089778-.	Scoping review	UK	38 results from 34 studies, majority randomised controlled trials or protocols	Various multiple long-term conditions (inc. cardiovascular, mental health, epilepsy, COPD, etc.)	Most digital tools were web-browser based using wearable/trackers or devices, some mobile devices identified; most interventions supported by a facilitator for goal setting, feedback, or monitoring	N/A
[9] Craven MP, Andrews JA, Lang AR, Simblett SK, Bruce S, Thorpe S, et al. Informing the Development of a Digital Health Platform Through Universal Points of Care: Qualitative Survey Study. JMIR Form Res. 2020;4(11):e22756-e.	Qualitative survey study	UK	Qualitative interviews with 28 subject matter experts (16 health care practitioners, 5 health care services researchers); 7 people with lived experiences of MS, epilepsy, or depression	Epilepsy, multiple sclerosis, and depression	Remote Assessment of Disease and Relapse (RMT) platform of wearables and mobile phone apps using remote monitoring and questionnaires;	Qualitative analysis in new methodology (Universal Points of Care) based on use case scenarios and views of participants on the use, acceptance, and value of a remote monitoring platform

Citation	Study type	Geography	Study population and sample size (or included articles for reviews)	Conditions that intervention addresses	Intervention	Outcome measures
[8] Doyle J, Murphy E, Gavin S, Pascale A, Deparis S, Tommasi P, et al. A Digital Platform to Support Self-management of Multiple Chronic Conditions (ProACT): Findings in Relation to Engagement During a One-Year Proof-of-Concept Trial. J Med Internet Res. 2021;23(12):e22672-e.	Longitudinal observational study	Ireland / Belgium	Patients with two or more of COPD, congestive heart failure, chronic heart disease and diabetes; 93 patients used platform until end of trial	COPD, congestive heart failure, chronic heart disease and diabetes	Monitoring of vitals (blood pressure, heart rate, etc.) and symptom tracking; recommended educational support based on data collected; remote access for care network (including informal carers) and a triage system for clinical staff	User engagement data, system usability scale (SUS) and participant interviews
[19] Fritz R, Wuestney K, Dermody G, Cook DJ. Nurse-in-the-loop smart home detection of health events associated with diagnosed chronic conditions: A case-event series. Int J Nurs Stud Adv. 2022;4:100081-	Case series analysis	USA / Australia	Patients with "multiple chronic health conditions"; 25 patients participated in study	Various multiple long-term conditions (heart failure, COPD, IBS, cancer, arthritis, etc.)	Monitoring of motion, light, temperature, and door usage by ambient sensors installed in the home; description of behaviour and events from nursing telehealth visits used to analyse data	Case study analysis to determine accuracy of monitoring for bathroom use and disrupted sleep in relation to health event reports
[20] Hernandez-Quiles C, Bernabeu-Wittel M, Barón-Franco B, Palacios AA, Garcia-Serrano MR, Lopez-Jimeno W, et al. A randomized clinical trial of home telemonitoring in patients with advanced heart and lung diseases. J Telemed Telecare. 2021:1357633X2110597.	Randomised controlled trial	Spain	Patients with heart or respiratory failure above certain thresholds, PALIAR score of 0-7, 18 or over; 510 patients participated in study randomised to two arms	Advanced heart or lung disease; various other multiple long-term conditions (hypertension, diabetes, depression, chronic kidney disease)	Usual care arm: frequent symptom and vital (blood pressure, heart rate, oxygen, etc.) registered on paper notebook, call centre for dietary and care recommendations; intervention arm: same as above with devices for real-time monitoring, digital questionnaires and alarm system	Primary: need for admission / emergency room visits at 45, 90 and 180 days; secondary: health care requirements, mortality, functional assessment, health related quality of life (Harmol), perceived satisfaction and cost-efficacy
[13] Kaimakamis E, Perantoni E, Serasli E, Kilintzis V, Chouvarda I, Cheimariotis G-A, et al. Applying translational medicine by Using the WELCOME Remote Monitoring System on Patients with COPD and Comorbidities. 2019 IEEE EMBS	Pilot study	Greece	Patients recruited from outpatient clinic of Pulmonary Department of tertiary hospital in Greece; 17 participated in study	Diabetes, congestive heart failure, anxiety/depression	Monitoring of vitals (heart and respiratory rate, blood pressure, etc.) with a sensor-vest and other bluetooth enabled devices; Decision Support System	Case study analysis and accuracy of alerts and data collection

Citation	Study type	Geography	Study population and sample size (or included articles for reviews)	Conditions that intervention addresses	Intervention	Outcome measures
International Conference on Biomedical & Health Informatics (BHI); 2019/05: IEEE; 2019.					(DSS) fires alerts based on thresholds	
[11] Kroenke K, Baye F, Lourens SG, Evans E, Weitlauf S, McCalley S, et al. Automated Self-management (ASM) vs. ASM-Enhanced Collaborative Care for Chronic Pain and Mood Symptoms: the CAMMPS Randomized Clinical Trial. J Gen Intern Med. 2019;34(9):1806-14.	Randomised controlled trial	USA	Patients with pain (musculoskeletal or widespread, persistent for 3 months or longer despite medication, moderate severity) plus psychiatric comorbidity (anxiety, depression, or both), 18 and above; 294 participants	Chronic pain, anxiety depression	Enhanced usual care arm: automated symptom monitoring and prompting of pain and mood self-management strategies; comprehensive care arm: nurse contact, optimised medication regimens and facilitated mental health care	Primary outcome: composite PAD (pain-anxiety-depression) consisting of BPI, PHQ-9 and GAD-7; secondary outcomes: HRQoL, disability, satisfaction and healthcare use.
[15] Lang C, Voigt K, Neumann R, Bergmann A, Holthoff-Detto V. Adherence and acceptance of a home-based telemonitoring application used by multi-morbid patients aged 65 years and older. J Telemed Telecare. 2022;28(1):37-51.	Longitudinal bicentric intervention study	Germany	Patients with multi-morbidity aged 65 or over; 177 patients included in study, 61 withdrawals	Various multiple long-term conditions (hypertension, type 2 diabetes, heart failure, chronic kidney disease, etc)	Monitoring of vital signs (blood pressure, heart frequency, etc.) using measuring devices and daily completion of questionnaires by patients; staff monitored data and sent further questions if required or contacted the patient for intervention	Data on adherence and participation and HRQoL (via GDS, SF-12 and Empowerment Scale)
[18] Lear SA, Norena M, Banner D, Whitehurst DGT, Gill S, Burns J, et al. Assessment of an Interactive Digital Health–Based Self-management Program to Reduce Hospitalizations Among Patients With Multiple Chronic Diseases. JAMA Network Open. 2021;4(12):e2140591.	Randomised clinical trial	Canada	Patients older than 19 years with 2 or more of the following (diabetes, heart failure, heart disease, chronic kidney disease or COPD); 229 participants randomised into two groups	Diabetes, heart failure, heart disease, chronic kidney disease, COPD	Self-monitoring and submission of vitals (blood pressure, weight) and symptom questions on internet-based platform; support from full-time nurse, dietician and exercise specialist; alert system based on failure to report symptoms or vitals exceeding targets	Primary outcome: all-cause hospitalisations from time of randomisation to end of 2 years; secondary outcomes: hospital length of stay, quality of life (SF-36v2), self-management (Health Education Impact Questionnaire), social support (Medical Outcomes Study Social Support Scale)

Citation	Study type	Geography	Study population and sample size (or included articles for reviews)	Conditions that intervention addresses	Intervention	Outcome measures
[17] Mallow JA, Theeke LA, Theeke E, Mallow BK. The effectiveness of mI SMART: A nurse practitioner led technology intervention for multiple chronic conditions in primary care. Int J Nurs Sci. 2018;5(2):131-7.	Prospective pre/post design study	USA	Patients over 18 with diabetes, obesity, hypertension, depression, or hyperlipidaemia; 30 participants	Diabetes, obesity, hypertension, depression	Monitoring of vitals with Bluetooth devices, use of app with notification for medication use, patient education, reminders to perform self-management, video conferencing for appointments, etc.	Quality of life (SF-36v2), loneliness (UCLA scale), depression (PHQ-9); biometrics including blood glucose mmol/L, systolic blood pressure mmHg and body weight
[22] Peretz D, Arnaert A, Ponzoni NN. Determining the cost of implementing and operating a remote patient monitoring programme for the elderly with chronic conditions: A systematic review of economic evaluations. J Telemed Telecare. 2016;24(1):13-21.	Systematic review	Canada	13 studies, all economic evaluations of remote monitoring	COPD, chronic heart failure, diabetes, hypertension, kidney disease, cancer, heart disease	Remote patient monitoring of one or more vital signs in conjunction with home nursing visits	N/A
[21] Roca S, Lozano ML, García J, Alesanco Á. Validation of a Virtual Assistant for Improving Medication Adherence in Patients with Comorbid Type 2 Diabetes Mellitus and Depressive Disorder. Int J Environ Res Public Health. 2021;18(22):12056.	Pilot study	Spain	Patients over 18 with type 2 diabetes and depressive disorder with poor medication adherence	Diabetes and depression	Virtual assistant app with medication reminders, remote monitoring by healthcare professional	Medication possession ratio (MPR), glycosylated haemoglobin (HbA1C) and PHQ-9
[12] Scheibe M, Lang C, Druschke D, Arnold K, Luntz E, Schmitt J, et al. Independent Use of a Home-Based Telemonitoring App by Older Patients With Multimorbidity and Mild Cognitive Impairment: Qualitative Study. JMIR Hum Factors. 2021;8(3):e27156-e.	Qualitative study	Germany	Patients with multi-morbidity and mild cognitive impairment aged 65 or over; 12 patients interviewed	Diabetes, hypertension, heart disease	Monitoring of vital signs via devices and completion of questionnaire by patient; educational videos and weekday monitoring of vital data values at care coordination centre	Information about use and experience, collected through qualitative interviews
[7] Sheng Y, Doyle J, Bond R, Jaiswal R, Gavin S, Dinsmore J. Home-based digital health technologies for older adults to self-manage multiple chronic conditions: A data-informed analysis of user engagement from a	Longitudinal observational study	Ireland / Belgium	Patients with two or more of COPD, congestive heart failure, chronic heart disease and diabetes, 60 years or older; 60 participants	COPD, congestive heart failure, chronic heart disease and diabetes	Monitoring of vitals (blood pressure, heart rate, etc.) and symptom tracking; recommended educational support based on data collected; remote access for	User engagement and retention data

Citation	Study type	Geography	Study population and sample size (or included articles for reviews)	Conditions that intervention addresses	Intervention	Outcome measures
longitudinal trial. Digit Health. 2022;8:20552076221125957-.					care network (including informal carers) and a triage system for clinical staff	
[16] Walker PP, Pompilio PP, Zanaboni P, Bergmo TS, Prikk K, Malinovschi A, et al. Telemonitoring in Chronic Obstructive Pulmonary Disease (CHROMED). A Randomized Clinical Trial. American Journal of Respiratory and Critical Care Medicine. 2018;198(5):620-8.	Randomised clinical trial	Various	Patients 60 years or older with a diagnosis of COPD GOLD grade II or higher, a history of acute exacerbation, smoking history of greater than or equal to 10 pack-years, one or more documented non-pulmonary chronic conditions. 312 participants randomised into two groups	COPD, heart failure, heart disease, hypertension, hyperlipidaemia , clinically significant sleep-disordered breathing	Intervention arm monitoring vitals using devices; algorithm to detect worsening with alert sent to study nurse; all participants telephoned every 3 months to complete study questionnaires	Primary outcomes: time to first hospitalisation and change in EuroQoL EQ-5D utility index score; secondary outcomes: rate of antibiotic/corticosteroid prescription, hospitalisation, COPD Assessment Tool, PHQ-9, Minnesota Living with Heart Failure questionnaire scores; quality-adjusted life years, healthcare costs
[5] Wang J, Cai C, Padhye N, Orlander P, Zare M. A Behavioral Lifestyle Intervention Enhanced With Multiple-Behavior Self-Monitoring Using Mobile and Connected Tools for Underserved Individuals With Type 2 Diabetes and Comorbid Overweight or Obesity: Pilot Comparative Effectiveness Trial. JMIR Mhealth Uhealth. 2018;6(4):e92-e.	Randomized controlled trial	USA	Patients with diabetes, BMI>25, aged 21 to 75, 26 patients	Type 2 diabetes, overweight	Mobile monitoring of diet, PA, weight, and blood glucose; mobile monitoring; or usual care. Mobile and paper groups received 11 face-to-face sessions	Feasibility, HBA1C, weight
[14] Ware P, Shah A, Ross HJ, Logan AG, Segal P, Cafazzo JA, et al. Challenges of Telemonitoring Programs for Complex Chronic Conditions: Randomized Controlled Trial With an Embedded Qualitative Study. J Med Internet Res. 2022;24(1):e31754-e.	Randomised controlled trial	Canada	Patients with 1 or more diagnosis of heart failure, uncontrolled hypertension and insulin-requiring diabetes aged 18 or over, 96 participants randomised into two groups	Heart failure, hypertension, diabetes	Intervention arm monitoring vitals using devices; symptom questions via smartphone app; actionable feedback provided to patients based on readings or alerts sent to nurses	Primary outcome: health status (SF-36); secondary outcomes: anxiety and depression, self-efficacy in chronic disease management and self-reported health service use