Intelligent Medicine 2 (2022) 41–47

Contents lists available at ScienceDirect

Intelligent Medicine

journal homepage: www.elsevier.com/locate/imed

Review

Mobile health technology: a novel tool in chronic disease management

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ARTICLE INFO

Keywords:
Mobile health technology
Chronic disease management

ABSTRACT

The successful control of chronic diseases mainly depends on how well patients manage their disease conditions with the aid of healthcare providers. Mobile health technology—also known as mHealth—supports healthcare practice by means of mobile devices such as smartphone applications, web-based technologies, telecommunications services, social media, and wearable technology, and is becoming increasingly popular. Many studies have evaluated the utility of mHealth as a tool to improve chronic disease management through monitoring and feedback, educational and lifestyle interventions, clinical decision support, medication adherence, risk screening, and rehabilitation support. The aim of this article is to summarize systematic reviews addressing the effect of mHealth on the outcome of patients with chronic diseases. We describe the current applications of various mHealth approaches, evaluate their effectiveness as well as limitations, and discuss potential challenges in their future development. The evidence to date indicates that none of the existing mHealth technologies are inferior to traditional care. Telehealth and web-based technologies are the most frequently reported interventions, with promising results ranging from alleviation of disease-related symptoms, improvement in medication adherence, and decreased rates of rehospitalization and mortality. The new generation of mHealth devices based on various technologies are likely to provide more efficient and personalized healthcare programs for patients.

1. Introduction

Mobile technology has become increasingly popular for the self-management of chronic diseases because of its high efficacy, accessibility, and cost-effectiveness, particularly during the COVID-19 pandemic as patients have experienced difficulties accessing medical services through face-to-face visits with healthcare providers [1–5]. Mobile health (mHealth) is defined by the World Healthcare Organization (WHO) as the use of mobile and wireless devices to support healthcare management [6]. Information and communication technologies for mHealth intervention include mobile phones, personal digital assistants, laptops, tablets, and wearable biometric monitors/sensors. mHealth interventions are organized into different categories for use by patients, healthcare providers, health system managers, and data services [7–8]; they offer an alternative to conventional clinical practice and can enhance the quality of patient care, facilitate the connection between healthcare providers and patients to increase patient engagement, and more importantly, achieve better health outcomes throughout the patient's disease journey. Some studies have shown that mHealth devices play a beneficial role in the control of chronic diseases [1-2,4–5,9–10], which are a health and economic burden for patients and society. mHealth technologies enable time- and location-independent management of multiple chronic conditions through the use of the communication networks. Many studies have investigated the efficacy of different mHealth interventions for chronic diseases such as cardiovascular diseases (CVD; eg, ischemic heart disease, cardiac failure, and hypertension)—which are the most life-threatening and account for the majority of deaths from long-term illness—as well as cancers, chronic respiratory diseases (eg, chronic obstructive respiratory disease(COPD) and asthma), diabetes mellitus (DM), chronic kidney disease (CKD), and chronic skin diseases (eg, psoriasis and atopic dermatitis).

The effects of mHealth interventions on long-term illnesses are evaluated using different outcome measures for clinical (eg, physiologic and disease-related biomarkers of disease control, rates of readmission/unplanned clinical visits, symptom assessments, adverse events, exercise capacity, disease-related mortality and quality of life (QoL), etc.), self-efficacy (eg, medication adherence, lifestyle changes, measures of patient engagement and knowledge of disease), and economic outcomes.

The aims of this review were as follows: (1) to summarize current applications of different types of mobile technology-based interventions; (2) to identify different types of mHealth intervention and describe their role(s) in facilitating chronic disease management; (3) to synthesize the existing evidence on the effects of mHealth interventions compared to

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https://doi.org/10.1016/j.imed.2021.06.003
Received 15 January 2021; Received in revised form 18 June 2021; Accepted 22 June 2021

standard healthcare approaches; and (4) to address the current limitations and future perspective of mHealth technology-based management of chronic diseases.

2. Methods

We reviewed high-quality studies on mHealth and its application to chronic diseases. The final synthetic analysis includes 65 frequently cited systematic reviews and randomized controlled trials (RCTs) investigating the efficacy of mobile technologies in chronic disease management. Both studies were identified by searching the Cochrane, PubMed, and Web of Science databases from 2010 to 2020. The chronic diseases discussed in this review include CVDs, chronic respiratory diseases, DM, cancer, chronic skin disease, and CKD. We searched relevant Medical Subject Headings terms including 'mHealth', 'mobile technology', 'telemedicine', 'telehealth', 'chronic disease', 'chronic kidney disease', 'cardiovascular disease', 'cancer', 'chronic respiratory disease', 'chronic skin disease', 'diabetes', and their abbreviations. Publications in English were selected.

3. Disease management and mobile technology

3.1. Characteristics of mHealth interventions

mHealth interventions for chronic diseases are diverse and employ various technological innovations and applications. In this review, we focus on the technologies used by patients to communicate with healthcare professionals in non-hospital settings. Based on the delivery channel of the intervention, mHealth applications can be broadly divided into the following categories: telecommunications (telecom) services, mHealth applications, Web-based technologies, social media, and wearable mHealth devices.

3.1.1. Telecom services

Telecom services, also known as telemedicine, involves the delivery of medical assistance through telecommunications technologies including phone services, mobile messaging services (short message service (SMS) or multimedia message service), interactive voice response, teleconferencing, etc. Mobile phone messaging has the advantages of being low cost, widely accessible, and simple to use and is one of the most widely studied mHealth interventions for chronic disease control in both developed and developing countries [11–19]. A systematic review of 371 studies up to 2018 found that SMS was the mHealth technology that was most widely used to facilitate different aspects of disease management [12] including medication compliance [13–14], lifestyle modification [15] self-management [16–17], and attendance [18] that can improve health behaviors and disease-related outcomes [12–19]. For instance, patients can consult and discuss their problems with clinical experts from a remote location through video conferencing using social applications or telecom devices. Such real-time interactive teleconsultation strengthens the relationship between patients and healthcare providers [9,12,20–21].

3.1.2. mHealth applications

Smartphone applications with specific functional modules are designed by multidisciplinary teams to address various health challenges. Some applications implement a single core function while others are multifunctional. For example, the "skin app" used for online skin cancer screening is a single-function smartphone application that has become popular in the field of dermatology [22–25].

3.1.3. Web-based technologies

Web-based technologies are defined as internet platforms and online support systems for the delivery of patient care, such as cloud storage of health data shared by patients and experienced clinicians, online health consultation, in-person medical appointment scheduling, and educational programs and videos.

3.1.4. Social media

Social media such as WeChat, Snapchat, Facebook, and Twitter are internet platforms that provide access to healthcare resources by offering medical knowledge and information, real-time consultation with clinical experts, outpatient visit scheduling, and peer-to-peer support especially for the younger generation, who account for the vast majority of users. A systematic review of 42 studies from 2010 to 2015 examining the current applications of social media in supporting chronic disease management found that a large proportion of research evaluated the impact of social media on cancer, DM, and CVD management [26–28]; and a recent RCT for a pulmonary rehabilitation intervention program using social media revealed that WeChat was used effectively to support COPD rehabilitation [29].

3.1.5. Wearable devices

Wearable mHealth devices include biometric sensors or monitors such as smart watches, bracelets, earphones, skin patches, a glucose-sensing lens, or other portable gadgets. The key feature of these devices is unobtrusive, noninvasive, constant tracking and recording of patients' clinically significant physiologic data such as temperature, blood pressure, pulse and respiratory rate, oxygen saturation, blood glucose, electrocardiogram (ECG) signal, and cardiac output as well as physical activity level and sleep pattern in response to environmental changes during patients' daily activities [5,30].

Different mHealth technologies are often integrated for specific clinical conditions. For instance, health data or clinical images acquired with smartphone applications, wearable sensors, or electronic monitors are uploaded to web-based data collection platforms. These data will be further reviewed and interpreted by health professionals or computerized systems. Feedback and recommendations can be delivered to patients either electronically via email/mobile messaging or telephone consultation or through face-to-face meetings [5,9].

3.2. Impact of mHealth interventions on different chronic diseases

In the following subsections, we discuss the application of mHealth technologies to CVD, chronic pulmonary disease, DM, cancer, chronic skin diseases, and CKD and their effects on clinical outcomes (eg, validated assessment of symptoms or biomarkers of disease control, rates of readmission/unplanned clinical visits, adverse events, exercise capacity, disease-related mortality, QoL, etc.); self-efficacy outcomes (eg, medication compliance, lifestyle changes, patient engagement and knowledge of the disease); and cost-effectiveness outcomes (eg, waiting time and cost). There is currently no evidence that mHealth interventions negatively impact chronic disease management [8-9,12,18,21,31–33].

3.2.1. CVD

mHealth interventions facilitate the prevention, monitoring, and management of CVDs such as atrial fibrillation, heart failure (HF), and myocardial infarction as well as rehabilitation [14,33–45]. Technological advances have led to the integration of mHealth tools and ECG monitoring, allowing close management and emergency care for patients with myocardial infarction [39]. In a systematic review and meta-analysis of 9 RCTs on the impact of mHealth technologies including smartphone applications, text messaging services, web-based technologies, telemedicine, and wearable monitors on the modification of risk factors (eg, obesity, hypertension, cholesterol, and glucose level) and prevention of adverse outcomes (eg, CVD events, hospital readmission, and deaths), mHealth interventions were found to lower CVD morbidity by reducing body mass index (−0.17 kg/m^2, 95% CI (0.32–0.01) kg/m^2, P =0.03, I^2=97%) and body weight (−2.77 lb (pound), 95% CI (4.49–1.05) lb, P <0.002, I^2=97%), but did not affect blood pressure or low-density lipoprotein cholesterol for secondary prevention of CVD. The use of mHealth technologies significantly decreased the relative risk (RR) of adverse CVD outcomes in specific cardiovascular risk populations (0.61, 95% CI: 0.46 - 0.80, P <0.001, I^2=22%) [40]. This result

Table 1 Effects of mHealth interventions on clinical outcomes in patients with CVDs compared with control interventions

Technology	CVD risk factors*	CVD events	Hospitalization	Mortality	QoL	Exercise capacity	Adherence
Multicomponent mHealth interventions	1/2 (+) 1/2 (+/−)	–	1/1 (+/−)	–	1/3 (+) 1/3 (+/−) 1/3 (−)	1/2 (++) 1/2 (+/−)	1/3 (++) 1/3 (+) 1/3 (+/−)
Web-based technologies	2/3 (++) 1/3 (+)	3/3 (+/−)	1/5 (++) 4/5 (+/−)	4/4 (+/−)	2/3 (++) 1/3 (+/−)	2/2 (++)	1/1 (++)
Mobile applications	2/2 (+/−)	–	–	–	–	–	2/2 (++)
Telecom services (SMS, telemonitoring program, etc.)	1/6 (++) 3/6 (+) 2/6 (+/−)	2/3 (++) 1/3 (+/−)	6/10 (++) 4/10 (+/−)	4/7 (++) 3/7 (+/−)	2/6 (++) 1/6 (+) 3/6 (+/−)	3/4 (++) 1/4 (−)	13/15 (++) 2/15 (+/−)

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group.

* Includes blood pressure, low-density lipoprotein, body mass index, weight loss, smoking cessation. CVD: cardiovascular disease; mHealth: mobile health; QoL: quality of life; SMS: short message service.

Table 2 Effects of mHealth interventions on clinical outcomes in patients with chronic respiratory disease compared with control interventions

Technology	Adverse COPD events (hospitalization and exacerbation)	Symptom control	QoL	Exercise capacity	Self-efficacy and behavioral changes*	Adherence
Multicomponent mHealth interventions	3/3 (+/−) –	1/7 (++) 6/7 (+/−)	2/8 (++) 6/8 (+/−)	4/4 (+/−)	4/4 (+/−)	–
Web-based technologies	3/3 (+/−)	1/4 (++) 3/4 (+/−)	4/4 (+/−)	2/2 (+/−)	3/4 (+/−)	–
Mobile applications	1/2 (++) 1/2 (+/−)	1/1 (+/−)	1/3 (++) 2/3 (+/−)	–	1/1 (+/−)	2/2 (+/−)
Telecom services (SMS, telemonitoring program, etc.)	4/4 (+/−)	4/4 (+/−)	5/5 (+/−)	1/1 (++)	2/2 (+/−)	–

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group.

* Behavioral changes includes improved physical activity, body mass index, smoking cessation, etc. COPD: chronic obstructive respiratory disease; mHealth: mobile health; QoL: quality of life; SMS: short message service.

was supported by another systematic review, which showed that most studies (79%, 22/28) reported positive effects of mHealth interventions on CVD management that were mainly attributable to high-frequency, personalized, interactive, and multifaceted care [41].

Table 1 summarizes the effects of different mHealth technologies on specific clinical outcomes in patients with CVD. Telemonitoring for HF was shown to be superior to standard care in terms of reducing the rates of CVD events (2/3), hospitalization (6/10), mortality (4/7), and exercise capacity (3/4) and potentially promoting behavioral changes or medication adherence [33,36,40–45]. Another systematic review found significant reductions in the risks of all-cause mortality (RR=0.60, 95% CI: 0.45–0.81) and HF-related hospitalizations (hazard ratio (HR)=0.86, 95% CI 0.61–1.21) with telemonitoring [43]. The absolute RR from different comparisons varied from 1.4% to 6.5% and from 3.7% to 8.2%, respectively. An increasing number of studies examining the health economic outcomes of mHealth interventions for CVD management have shown that they can increase quality-adjusted life years compared to standard care [46].

3.2.2. Chronic respiratory disease

Patients with chronic respiratory diseases such as asthma and COPD require long-term routine medical care by specialists to maintain a stable status. Self-management supported by mHealth interventions may improve the clinical outcomes of these patients. There are currently over 300 mobile applications for people with COPD available on the Android and iOS app platforms with functional features such as self-monitoring, personal feedback, and patient education [44]. One study found that a WeChat account with multiple functional modules for pulmonary rehabilitation in COPD patients had comparable efficacy to face-to-face interventions as measured by health-related QoL, dyspnea status, and self-efficacy, with variations over time [29]. The effects of mHealth interventions on outcomes of COPD patients are shown in Table 2. Health-related QoL was the most frequently reported outcome, followed by symptom control, adverse events, behavioral modification, functional exercise capacity, and adherence. Most studies demonstrated the noninferiority of mHealth interventions compared to standard care for COPD management, with a few demonstrating superiority [29,47–52]. Two of 8 studies reporting QoL as an outcome found a significant improvement using a combination of mHealth technologies compared to standard care. One study showed that the use of mobile applications increased asthma-related QoL scores compared to standard care in both the mental and physical components of the 12-Item Short Form questionnaire at the 6 month-follow up (mean difference (MD)=6.00, 95% CI: 2.51 - 9.49 and MD =5.50, 95% CI: 1.48 –9.52, respectively), with increased lung function (as measured by peak expiratory flow rate) at 4, 5, and 6 months (MD =27.80, 95% CI: 4.51–51.09; MD =31.40, 95% CI: 8.51- 54.29; and MD =39.20, 95% CI: 16.58–61.82, respectively) [53]. There is currently a lack of studies reporting adherence outcomes.

Although it is early to draw conclusions regarding the effectiveness of specific types of mobile technology, the overall results indicate that mHealth interventions are a useful tool for monitoring chronic respiratory diseases [47–53].

3.2.3. DM

The most widely used mHealth intervention among DM patients is glucose monitoring. Mobile technologies allow remote glucose monitoring by healthcare professionals, who can provide support by advising on insulin dose adjustments and changes in diet and exercise and evaluating hypoglycemia symptoms [50]. Glucose-sensing lenses, transdermal monitoring patches, and other wearable sensors enable continuous blood glucose measurement with point-of-care diagnostics [30,39]. The effectiveness of different mHealth technologies for DM is summarized in Table 3. Most of the evidence to date indicates that mHealth interventions (mobile applications, telehealth, and combined mHealth interventions) improved glycemic control compared to standard care. The improvements in glycemic index were found to be relatively consistent

Table 3 Effects of mHealth interventions on clinical outcomes in patients with diabetes mellitus compared with control interventions

Technology	Glycemic control	Weight loss and BMI changes	Behavioral changes (physical activity, diet intake, etc.)	QoL
Multicomponent mHealth interventions	3/4 (++) 1/4 (+)	2/2 (++) –	1/1 (+/−) –	–
Mobile applications	8/12 (++) 1/12 (+) 3/12 (+/−)	2/6 (++) 4/6 (+/−)	4/5 (++) 1/5 (+/−)	1/3 (+) 2/3 (+/−)
Telecom services (SMS, telemonitoring program, etc.)	4/6 (++) 1/6 (+) 1/6 (+/−)	4/5 (++) 1/5 (+/−)	4/4 (++) –	1/1 (++) –

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group. BMI: body mass index; mHealth: mobile health; QoL: quality of life; SMS: short message service.

Table 4 Effects of mHealth interventions on clinical outcomes in patients with cancer compared with control interventions

Technology	Symptom control	QoL and well-being	Survival	Functional status	Self-efficacy	Adherence
Web-based technologies	7/9 (++) 2/9 (+/−)	4/7 (++) 3/7 (+/−)	2/2 (++) –	1/1 (++) –	1/2 (++) 1/2 (+/−)	–
Mobile applications	2/2 (++) –	3/4 (++) 1/4 (+/−)	–	1/1 (++)	1/1 (++)	1/1 (++)
Telecom services (SMS, telemonitoring program, etc.)	9/16 (++) 7/16(+/−)	2/3 (++) 1/3 (+/−)	–	1/1 (+/−)	2/4 (++) 2/4 (+/−)	1/1 (+/−)

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group. mHealth: mobile health; QoL: quality of life; SMS: short message service.

across various reviews, particularly in patients with type 2 DM. Two meta-analysis of studies comparing mobile application interventions and standard care showed that use of the former decreased hemoglobin A1c −0.40% to −0.48% (P =0.007 and <0.001, respectively) [54–55]. Better glycemic control was achieved by patients with type 2 DM than among those with type 1 DM, who showed significant fluctuations in blood glucose level (−0.67% *vs.* −0.36%). Both telehealth and mobile application interventions showed encouraging results in terms of lifestyle modifications such as dietary changes and physical activity, possibly contributing to better disease control.

The adoption of technology in teleophthalmology has improved the accessibility of eye examinations for DM patients [31]. For example, telemedicine using digital retinal images is a highly accurate and sensitive tool for diabetic retinopathy screening in DM patients [56–57].

3.2.4. Cancer

The noninferiority of mHealth interventions to standard care was demonstrated in 2 meta-analysis that reported outcomes of cancer-related symptoms (eg, anxiety, depression, distress, fatigue, pain, sexual dysfunction, etc.) in patients with cancer, most patients showing greater improvements in disease management using telehealth interventions (9/16 studies), web-based interventions (7/9 studies), and mobile applications (2/2 studies). mHealth technologies also enhanced QoL as well as emotional well-being (Table 4). The beneficial effects of mHealth technologies are supported by a recent Cochrane review. A quantitative analysis of evidence from 32 studies on various cancer types indicated that cancer-related symptoms such as depression (9 trials with change scores (CS) ranging from standard mean difference (SMD) =−2.2 (95% CI: −2.7 to −1.7) for colorectal cancer to SMD=0.3 (95% CI: 0.04–0.5) for mixed cancers), anxiety (5 trials, with CS ranging from SMD =−5.1 (95% CI: −6.1 to −4.1) for breast cancer to SMD =−0.3 (95% CI: −0.3 to 0.9 for prostate cancer)), fatigue (6 trials, with CS ranging from SMD =−0.9 (95% CI: −1.5 to −0.3) for breast cancer to SMD =0 (95% CI: −0.2 to 0.2) for mixed cancers), and emotional distress were likely improved by mHealth interventions [58]. Two trials evaluating survival outcomes of patients using a web-based platform to collect self-report data with feedback from healthcare professionals in cases of worsening symptoms [59–60] showed that web-based follow-up improved overall survival (8.7 *vs.* 8.0 months, P = 0.004 and 19.0 *vs.* 12.0 months, HR =0.32, P = 0.002). This beneficial effect may allow detection of early relapse and improve health status upon relapse [60]. Additional data are needed to draw more definitive conclusions regarding the benefits of mHealth on other clinical outcomes such as functional status, self-efficacy, and adherence.

A thematic analysis of cancer survivors' experience underscored the advantages of using telehealth interventions to minimize disruption to patients' daily lives by facilitating engagement for personal care, reducing the therapeutic burden, and providing support through real-time monitoring [61]. Notably, the study also considered factors that could negatively influence patients' attitude toward telehealth interventions such as lack of in-person contact, limited accessibility to telehealth devices, and over-reliance on professionals through telehealth services.

Most research on the beneficial role of mobile technologies in cancer monitoring has focused on the use of mHealth interventions in cancer screening for early detection [20-21,58,61–68]. Early diagnosis and treatment of occult cancer can improve prognosis and overall survival. Given the visual inspection aspect of dermatology, skin cancer assessment using telehealth technologies is a significant challenge. Dermatologists can examine uncharacterized skin lesions in digital images sent to them by the patient or via real-time interactive video conferencing [34]. Although the accuracy of teledermatology has not been shown to be superior to traditional face-to-face diagnosis, it is suggested that with the use of an appropriately defined threshold, the diagnostic accuracy may be sufficiently high for the diagnosis of most suspicious skin lesions and referral to specialists for a follow-up [34,62,69]. In this manner, teledermatology increases the likelihood of follow-up in patients with abnormalities detected during screening. Recent studies have also demonstrated the use of artificial intelligence-based mobile applications as an alternative to visiting a dermatologist for early diagnosis and cancer prevention. When there is suspicion of melanoma or other skin cancers, mobile applications for the skin can identify lesions with a high risk of malignancy from images immediately after the photo is taken using built-in algorithms. However, the diagnostic accuracy of such mobile applications is not satisfactory, with a relatively high rate of missed detection [65,70]. Thus, skin cancer screening with current artificial intelligence-based mobile applications does not meet clinical standards. Additionally, there are some potential drawbacks associated with these applications such as delays in medical engagement due to false reassurance.

Table 5 Effects of mHealth interventions on clinical outcomes in patients with chronic skin diseases compared with control interventions

Technology	Symptom control	Quality of life	Adherence
Web-based technologies	3/4 (+/−) 1/4 (++)	4/4 (+/−)	1/1 (+/−)
Mobile applications	1/1 (+)	1/1 (+/-)	1/1 (+)
Teledermatology	3/4 (+/−) 1/4 (++)	1/1 (+/-)	1/1 (+/−)

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group. mHealth: mobile health.

3.2.5. Chronic skin disease

Teledermatology is defined as the use of communication and information technologies to deliver dermatologic care. It is one of the best-characterized and fastest-growing mHealth interventions since its introduction in 1997 in rural communities as an alternative to traditional clinical visits [71]. The most widely used method of dermatologic consultation using mobile technology is the store-and-forward system, followed by live-interactive interventions and mixed interventions combining both of these technologies [34,72]. Store-and-forward applications offer dermatologic consultation through a process in which patient data (eg, digital images) are transmitted, stored, and forwarded to specialists for further assessment. With live interactive technologies such as video conferencing, patients can directly pose questions to doctors and receive immediate responses. Besides skin cancer diagnosis, teledermatology has also been applied to the management of chronic skin diseases such as psoriasis and atopic dermatitis [31,52,67–75], although there is a lack of systematic reviews on this topic. A recent Cochrane review article of the effects of mobile technologies on the relationship between healthcare providers and patients found that mHealth applications allowed early assessment and timely referral for people with skin problems (with a median delay of 4 days compared to 40 days with standard care; MD −40.5 days, 95% CI −23 to −58) [31]. Table 5 summarizes the results of recent RCTs investigating the effects of mHealth interventions on the management of psoriasis and atopic dermatitis. All included studies reported outcomes with mHealth interventions that were non-inferior to those achieved with standard care [52,76–82]; two studies reported the superiority of a mobile application and online monitoring for symptom control and medication adherence; and a study of 122 psoriasis patients demonstrated superior effects on short-term medication adherence (P = 0.004) and symptom reduction measured by Lattice System Physician's Global Assessment (P =0.047) with the mobile-based intervention after 8 and 26 weeks, although the results were not statistically significance [83]. A 1-year randomized clinical trial showed a long-term improvement in adherence (P =0.08) and psoriasis severity index (P =0.038) in patients who received online intervention, although the results must be interpreted with caution because of the small sample size and high rate of discontinuation [76].

More rigorous systematic analyses are needed in order to assess the clinical significance of mHealth interventions for skin disease management. Nonetheless, interventions delivered using mobile technology are generally accepted as a valid healthcare practice in dermatology.

3.2.6. CKD

To prevent CKD from progressing to end-stage renal disease, patients must be closely monitored by nephrologists in terms of symptoms and medication, dietary sodium intake, and fluid management. The impact of mHealth interventions on disease management in various CKD patients including those on dialysis or who have undergone renal transplantation are summarized in Table 6. Electronic medication-dispensing devices monitored by text messages or an application have resulted in clinically significant improvements in patient adherence [82–84]. A similar effect was reported in a clinical trial using smartphone urinalysis testing for hypertension patients with a high of CKD (28.9% *vs.* 18.0% with standard care, odds ratio (OR) =1.85, 95% CI: 1.37 - 2.49) [85]. In contrast to combined interventions, mobile medication applications alone did not significantly improve adherence to immunosuppressive therapy among kidney transplant recipients, as measured by nonadherence rate (mobile group, 65.0% vs control group, 62.1%, OR=1.14, 95% CI: 0.53 - 2.40, P =0.89) and self-reported adherence (P =0.42) [86]. A recent Cochrane systematic review evaluating the effectiveness of health-related technologies in CKD did not yield meaningful findings because of the poor quality of the current evidence base due to the heterogeneity of study designs, populations, technologies, and intervention types [87].

4. Future perspective

Given the increasing number of people with chronic diseases, many efforts have been made to increase the accessibility of traditional healthcare over the disease course by reducing travel over long distances and long wait times due to the heavy workload of healthcare providers [88]. The recent outbreak of coronavirus disease of 2019 (COVID-19) has accelerated the development of mHealth solutions that have transformed standard health management, which usually requires patients and physicians to be physically present together in a workspace (eg, hospital or doctor's office) [1,4–5,89]. Mobile technologies such as wearable devices, smartphones, and web-based applications can support remote monitoring and diagnosis without personal contact [5,30]. More studies on the contribution of different mHealth interventions to health outcomes are expected. Building on the existing evidence, more personalized and effective healthcare programs can be established by integrating multiple mHealth modalities addressing different aspects of chronic disease management.

Table 6 Effects of mHealth interventions on clinical outcomes in patients with chronic kidney disease compared with control interventions

Technology	Adverse events (mortality, hospitalization, rejection episodes)	QoL	Symptom control*	Self-efficacy	Adherence
Multicomponent mHealth interventions	1/4 (++) 1/4 (+) 2/4 (+/−)	–	2/2 (+/−)	–	4/4 (++)
Web-based technologies	–	–	1/1 (+/−)	–	–
Mobile applications	–	–	–	–	1/1 (+/−)
Telecom services (SMS, telemonitoring program, etc.)	1/3 (++) 2/3 (+/−)	2/3 (++) 1/3 (+/−)	1/5 (++) 1/5 (+) 3/5 (+/−)	1/1 (+/−) –	1/1 (+/−) –

(+/−): No difference; (+): superior to control group without significance; (+ +): superior to control group with significance (P <0.05); (−): inferior to control group.

* Symptom improvement was measured by blood chemistry, renal function, and control of complications, etc. mHealth: mobile health; QoL: quality of life; SMS: short message service.

5. Conclusion and limitations

The current evidence points to positive trends in mHealth interventions for chronic disease management. Emerging technologies are likely to transform the delivery of healthcare, especially for rural and underserved populations. Although the number of studies focusing on mHealth interventions and its applications has increased considerably over the past decade, most have been conducted in developed countries, with only a small number carried out in low-/middle- income countries [90–93]. Furthermore, because of the variability of the data, there is limited knowledge of the effects of specific mHealth modalities on different patient populations with long-term illnesses. Nonetheless, greater improvements were generally observed among patients who were using more intensive and complex interventions [20–21,29,91,93]. Most of the systematic reviews to have highlighted the challenges of data synthesis due to underpowered evidence of poor methodologic quality (eg, a short follow-up period, poor study design, small sample size, and high risk of bias), which has prevented researchers from drawing meaningful conclusions. The absence of reliable data on the long-term effects and cost-effectiveness of mHealth monitoring strategies makes it difficult to determine their actual value. Future studies need to use standardized methods to synthesize the evidence from different studies and expand the evidence for the effective translation of mHealth approaches into clinical practice.

Conflicts of interest statement

The authors declare that there are no conflicts of interest.

Funding

This study was funded by the National Natural Science Foundation of China (Grant Nos. 81472898 and 81773349).

Author contributions

Yi Zhao conceived and designed the analysis, and made critical revision; Kaman Fan wrote the paper, collected the data, contributed data or analysis tools and performed the analysis.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.imed.2021.06.003.

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