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REVIEW

The Effect of Mobile Health (mHealth) Interventions on Clinical Outcomes and Self-Management Behaviours in Individuals with Metabolic Syndrome: A Narrative Review of Evidence

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ABSTRACT

Introduction: There has been an exponential growth in mobile health (mHealth) technology for self-management of chronic conditions including metabolic syndrome (MetS). This narrative review aims to summarise the evidence on the effect of mHealth interventions on clinical outcomes and/or self-management behaviours among individuals with MetS or its components. **Methods**: Literature search for original research articles on mHealth for self-management of MetS or any of its components (type 2 diabetes mellitus, hypertension, dyslipidaemia, and obesity) from 2010-2021 was conducted using Web of Science, Scopus, PubMed, Cochrane Central Register of Controlled Trials, Google Scholar, SAGE and ScienceDirect. Keywords such as mHealth, effectiveness, self-management, MetS, hypertension, type 2 diabetes mellitus, dyslipidaemia and obesity were used. Articles in languages other than English, without access to full-text, outcomes unrelated to the effectiveness, and involved individuals aged <18 or >80 years old were excluded. All study designs were included except for study protocols. **Results:** A total of 184 potential papers were retrieved. Of these, 137 were excluded as they did not meet the inclusion/exclusion criteria. Consequently, 47 papers were included. Of these, 38 studies demonstrated effect of mHealth interventions in improving clinical outcomes (blood pressure, glycated haemoglobin, lipid profile, weight) and/or improvement in self-management behaviours (home blood pressure or blood sugar monitoring, exercise, diet or medication adherence) among individuals with MetS or its components. Only 12 studies were conducted in primary care. Apart from mHealth technologies, multifaceted elements such as doctor-patient interaction and wearable devices were also shown to be effective. **Conclusion:** This narrative review suggests that mHealth interventions may have positive effect on clinical outcomes and/or self-management behaviours among individuals with MetS and its components. This evidence should support development and evaluation of mHealth interventions to suit the needs of the Malaysian population, especially in primary care.

KEYWORDS: mHealth, chronic care model, self-management, metabolic syndrome, primary care

INTRODUCTION

Metabolic Syndrome (MetS) is characterised by the clustering of cardiovascular (CV) risk factors which include elevated blood glucose, elevated blood pressure (BP), central obesity and dyslipidaemia [1]. Individuals with MetS are five times more likely to develop T2DM [2, 3]. According to a systematic review of 37 studies involving more than 170,000 patients, MetS doubles the likelihood of cardiovascular events, namely myocardial infarction (heart attack) and cerebrovascular accident (stroke) [4].

Over the years, several diagnostic criteria for MetS were developed and these include the 2002 National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (NCEP-ATP III) [5], the 2005 International Diabetes Federation (IDF) worldwide definition for MetS [2] and the 2009 Joint Interim Statement (JIS) on MetS definition by the IDF Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis

Society; and International Association for the Study of Obesity [1].

MetS has become a global epidemic [6], not only in the western population, but its prevalence is escalating in the Asian population [7]. In the Asia-Pacific region, approximately 20% of the adult population were affected by MetS [7]. In Malaysia, MetS affects 25% – 40% of the adult population [8]. The JIS definition gave the highest overall prevalence (43.4%) compared with NCEP-ATP III (26.5%) and IDF (37.4%). Therefore, it should be recommended as the preferred diagnostic criterion to diagnose MetS in Malaysian adults [9]. MetS is also affecting the younger generation. In a pooled analysis of 26,609 participants' data aged 18-30 years old from 34 studies, MetS was present in 4.8% – 7% of young adults [10]. In Malaysia, the prevalence of MetS components such as obesity, dyslipidaemia, hypertension, and diabetes has increased rapidly over the last decades, especially in the younger generations [11]. The aggregation of CV risk factors that characterise MetS in the younger generation is the main contributing factor towards the premature cardiovascular disease (CVD) epidemic in Malaysia [12]. Premature coronary artery disease accounted for 10% – 15% of acute coronary syndrome (ACS) [12]. The mean age of individuals with ACS at admission in Malaysian hospitals was 58.6 years old, of which 23.8% were below the age of 50 years [13]. This is much younger compared with our Asian counterparts in the neighbouring countries such as Singapore and Thailand [14].

Identifying the causes for and reducing the incidence of premature CVD is a key national priority in Malaysia [15], and this includes improving the management of MetS and its components among the younger generation in the primary care setting [16]. Management of MetS is complex, and it involves managing the multiple CV risk factors that lead to complications. One of the prompting strategies to strengthen the management of MetS in primary care is the incorporation of the Chronic Care Model (CCM) into the health system [17]. It consists of six interrelated elements which include healthcare organisation, clinical information system, delivery system design, patient self-management support, decision support and use of community resources [18]. The CCM focuses on developing productive interactions between informed, actively engaged patients with proactive and prepared healthcare teams [17, 19]. It is one of the best models to improve outcomes of various long-term conditions, including components of MetS [20-26].

Out of the six elements, self-management support is one of the most fundamental components of CCM [19]. It incorporates intervention strategies which empower patients with knowledge, skills and confidence to change their lifestyle and manage their own health [19, 27]. Patients need support from their healthcare providers to achieve an optimum level of self-management behaviour. Therefore, inclusion of self-management programmes in the management of MetS components is recommended by several clinical practice guidelines in order to improve health outcomes [28, 30].

In the past decade, there has been an exponential growth in mobile health (mHealth) technology for self-management of chronic conditions including MetS [31-38]. However, most of the self-management systems available in the market were developed in the Western countries and high-income Asian countries such as Japan and South Korea [39-42]. In Malaysia, patient self-management tools were previously developed using paper-based materials e.g., self-management booklet [43]. Of note is the EMPOWER-PAR Project, where our research group has designed and developed the Global CV Risks Self-Management Booklet© as part of a multifaceted intervention program based on the CCM [43]. The effectiveness of this self-management booklet in improving clinical outcomes for diabetes has already been proven [44]. However, paper-based self-management booklets are less appealing to the younger generations as they prefer to browse the internet through their mobile phones as the primary source of health information [45, 46]. In 2017, 49% of the population in Malaysia used mobile phones. This number is estimated to increase to more than 21.8 million by 2023 [47]. Mobile phone users in Malaysia spent an average of 66 minutes daily on mobile apps [47]. The growth in the mobile phones usage in Malaysia unlocks the potential to transform the management of MetS in primary care using mHealth technology.

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With regards to the systematic review of evidence and meta-analysis, we only found one study that appraised the evidence on technology-mediated interventional approach to the prevention of MetS [39]. There is a gap in the literature with regards to the summary of evidence on the effect of mHealth technology in improving outcomes in individuals with MetS and its various components. Thus, this narrative review aims to summarise the evidence on the effect of mHealth interventions on clinical outcomes and self-management behaviours among individuals with MetS or its components.

MATERIALS AND METHODS

An extensive electronic search of the literature was conducted using Web of Science, Scopus, PubMed, Cochrane Central Register of Controlled Trials (CENTRAL, The Cochrane Library), Google Scholar, SAGE, and ScienceDirect. The search was conducted to look for original research articles written in English on mobile apps or mobile health technology in the self-management of MetS or any of its components (hypertension, diabetes, dyslipidaemia, obesity) from 2010-2021. The following search keywords were used: mobile health application, mobile health app, mHealth, mobile health technology, effectiveness, chronic care model, self-management, metabolic syndrome, hypertension, diabetes, dyslipidaemia and obesity. The exclusion criteria were articles in languages other than English, articles without access to the full paper, outcomes that were not related to the effectiveness of mHealth app in MetS or its components, and involved individuals aged < 18 or > 80 years old. All study designs were included except for study protocols. The reference lists of the original research articles were also checked for additional references. The retrieved articles were compiled and managed using EndNote 20 software according to MetS or its components (hypertension, diabetes, dyslipidaemia, and obesity). The search was carried out using multiple databases, which resulted in retrieving duplicate citations which were then removed using the EndNote 20 software. The search results were filtered by title and abstract after deduplication. The full texts and the articles that did not meet the inclusion criteria were removed.

The papers which were included were then assessed comprehensively. The papers were classified into types of diseases (a) MetS (b) T2DM (c) hypertension (d) dyslipidaemia (e) obesity. The following information was extracted and compiled: I) author name; II) year of publication; III) study title; IV) population size; V) subjects' age range; VI) the country where the study was conducted; VII) study design; VIII) tools; and IX) findings of the study. The findings of the study were further defined into the 'outcomes of interest' which represents the improvement in clinical outcomes i.e., BP, glycated haemoglobin (HbA1c), lipid profile, weight, as well as improvement in self-management behaviours (home BP or blood sugar monitoring, exercise, diet or medication adherence). Descriptive explanation of the study characteristics and outcomes of interest were tabulated. Figure 1 shows the flowchart of the screening and reviewing process to assess the eligible papers to be included in the study.

RESULTS

A total of 184 potential papers on the effect of mhealth technology to support self-management were retrieved. Papers excluded were those lacking access to the full text (n=1), duplicates (n=5), and articles with titles and abstracts that did not match the objective of this review (n=42). As a result, 136 full-text papers were assessed further. Out of these, 89 full-text papers with no outcome of interest were excluded. The content of the papers that were not related to intervention associated with mhealth apps was not considered as an outcome of interest. Finally, 47 original papers were included in the review. Out of these, 9 papers were studies on MetS, 16 papers were on T2DM, 10 papers were on hypertension, 1 paper was on dyslipidaemia and 11 papers were on obesity. Descriptive explanation of the study characteristics (population and site; study design; tool) and outcomes of interest are described in Tables 1-5 according to the types of diseases. Out of 47 papers of varying study designs, 38 demonstrated effect of mHealth intervention in improving outcomes of interest among individuals with MetS or its components.

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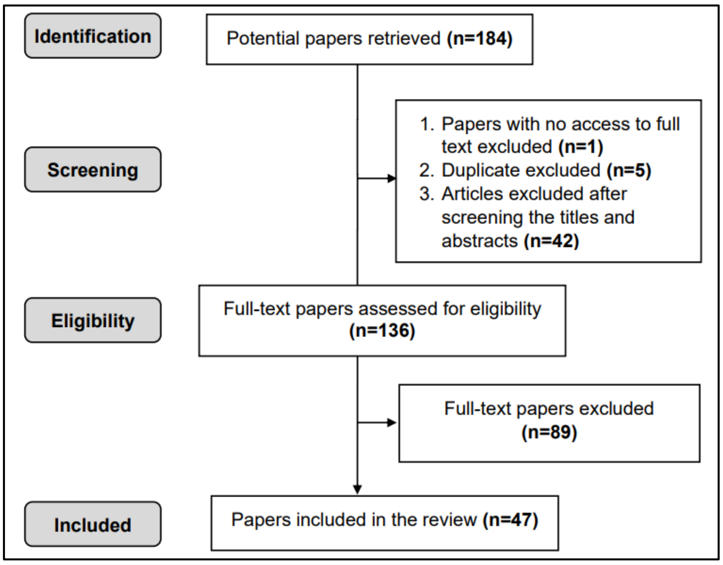

Figure 1 Screening process for the literature review

Metabolic Syndrome (MetS)

Table 1 summarises the findings of 9 papers of varying study designs on the effect of mHealth apps among individuals with MetS. Three papers were randomised controlled trials (RCT), 3 papers were pre-post intervention studies, 2 papers were quasi-experimental studies and 1 study was a non-randomized controlled trial.

Seven out of 9 papers demonstrated that mHealth interventions had an effect in improving outcomes of interest among patients with MetS. One of the studies of not is the RCT conducted by Oh et al. on the effect of the SmartCare app for weight management involving 422 patients with MetS in 2015 [48]. The intervention group that received SmartCare services (mobile phone with SmartCare app, body composition monitors and pedometer) portrayed greater reduction in body weight (2.21kg vs. 0.77kg) and body mass index (BMI) (0.8kg/m^2 vs. 0.2kg/m^2) at 24-week post intervention compared to the control group [48]. Another study of note is the RCT conducted by Cho et al. on smartphone-based lifestyle coaching app in a community-dwelling population with moderate metabolic abnormalities [49]. This 3-arm parallel-groups RCT involved 129 individuals with MetS in Seoul, South Korea [49]. Participants in the intervention groups used the smartphone-based weight management app for 6 months with or without persistent lifestyle coaching modification. The results demonstrated that the app with or without persistent lifestyle modification coaching had an effect in reducing weight and body fat mass [49]. Participants who used the app with personalized coaching had greater body weight reductions (app with personalized coaching: - 0.96kg vs. app only: - 0.35kg vs. control: - 0.12kg) and body fat mass reduction (app with personalized coaching: - 0.79kg vs. app only: - 0.64kg vs. control: - 0.13kg) [49].

Two studies showed no evidence of intervention impact of mobile apps in patients with MetS. Takeyama et al. conducted a non-randomized controlled trial on health guidance app to improve motivation, adherence to lifestyle changes and indicators of metabolic disturbances [waist circumference (WC), systolic blood pressure (SBP), diastolic blood pressure (DBP), HbA1c and high-density lipoprotein cholesterol (HDL-c)] among 102 Japanese civil servants in Hiroshima, Japan. There was no significant difference in outcome measures between the groups was observed at 6-month post intervention [50]. Petrella et al. conducted an RCT on the effect of the mHealth app among 149 participants with cardiometabolic risk factors aged between 18 to 70 years in Canada [51]. Participants receiving exercise prescription alone had a greater reduction in SBP compared to those receiving mHealth app intervention (- 8.7mmHg vs. - 3mmHg) at 12-weeks [51]. However, the reductions in DBP, WC, HbA1c, low-density lipoprotein cholesterol (LDL-c), and total cholesterol (TC) were similar between both groups, with no change in HDL-c for either group at 52-weeks follow-up [51].

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Table 1 Effect of mHealth self-management apps for individuals with MetS

No.	Author and Title	Study Population and Site	Study Design	Tool	Findings
1.	Lee et al. (2020) [52]	59 nursing students aged <30 years; Daegu and Keimyung, South Korea. Community	Quasi-Experimental Study	e-Motivate4Change Program (mobile app and wearable devices)	Significant reductions in cholesterol and BMI in the intervention group compared to the control group at 3-month post intervention.
2.	Takeyama et al. (2020) [50]	102 participants aged between 20 to 65 years; Hiroshima, Japan. Community	Non-Randomized Controlled Trial	Hiroshima Health Note (built-in features to monitor heart rate (HR), weight, daily steps, a feature to record BP, which can be accessed as a smartphone app or through a website)	Both intervention and control groups showed significant reductions in WC, DBP and HbA1c and an increased in HDL-c at 6-month post intervention compared to the baseline. No significant difference between the groups was observed.
3.	Cho et al. (2020) [49]	129 participants aged between 30 to 59 years; Seoul, South Korea. Community	Randomised Controlled Trial	Noom Inc. (smartphone-based weight management app)	The app with or without persistent lifestyle modification coaching was effective in reducing weight and body fat mass. Participants who used the app with personalized coaching had greater body weight reductions.

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4.	Lee Young Ju. (2020) [53]	100 participants with at least one MetS risk factors, aged between 20 to 70 years; Gyeongbuk, Korea. Community	Pre-Post Intervention	Mobile Health Care Project (mobile app via Bluetooth and a mobile-connecting device such as activity measuring tools on their smart phones)	Significant reductions in SBP, DBP, fasting blood sugar (FBS), WC, triglyceride and significant increment in HDL-c were found at 6-month post intervention compared to baseline.
5.	Huh et al. (2019) [54]	20 patients with MetS aged between 36 to 50 years; Busan, South Korea. Secondary Care	Pre-Post Intervention	A wearable device (Coffee WALKIE +Dv.3, GC Healthcare CI, Korea) and mobile app for exercise self-feedback	Significant reductions in SBP and DBP were found in participants at 12-week post intervention compared to baseline. MetS resolved in 9 of 20 participants (45%).
6.	Toro-Ramos et al. (2017) [55]	159 adults aged between 20 to 60 years; Seoul Metropolitan City Government and Life Insurance Foundation (LIF), Seoul, South Korea. Community	Quasi-Experimental Study	NOOM app and weight loss-coaching intervention (nutrition and physical activity)	Significant reductions in body weight, body fat, abdominal visceral fat, FBS and lipid parameters were observed at 15-week and at 52-week follow-up.

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7.	Oh et al. (2015) [48]	442 obese patients with MetS aged between 35 to 65 years; Seoul, South Korea. Secondary Care	Randomised Controlled Trial	SmartCare Services (mobile phone with SmartCare app, body composition monitors and pedometer)	Participants in the intervention group showed greater reductions compared to the control group in body weight and BMI at 24-week post intervention.
8.	Petrella et al. (2014) [51]	149 participants aged between 18 to 70 years; Huron-Perth and Grey-Bruce counties (Ontario, Canada). Community	Randomised Controlled Trial	Smartphone data portal and a kit (Blackberry equipped with 'Healthanywhere' health monitoring app, a Bluetooth enabled blood pressure monitor, a glucometer with Bluetooth adapter and a pedometer)	Improvement in SBP was greater in the control group compared to the intervention group at 12-week but the improvements in DBP, WC, HbA1c, LDL-c and TC were similar in both groups, with no change in HDL-c for either group at 52-week follow-up.
9.	Stuckley et al. (2013) [35]	12 adults with at least two MetS risk factors, aged 44 to 69 years; Western Ontario, Canada. Community	Pre-Post Intervention	Individualised exercise prescription and a mHealth technology kit (app to monitor BP, blood glucose, physical activity, and body weight)	The 8-week mHealth exercise intervention approach improved MetS risk factors with improvement in SBP compared to baseline (134 mmHg vs. 134 mmHg).

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Type 2 Diabetes Mellitus (T2DM)

Table 2 summarises the findings of 16 papers of varying study designs on the effect of mHealth apps among individuals with T2DM. Thirteen papers were RCT, 1 paper was a quasi-experimental study, 1 paper was a longitudinal cohort study and another 1 paper was a single-arm feasibility study.

Thirteen out of 16 papers demonstrated that the apps had an effect in improving outcomes of interest among individuals with T2DM. Of note is the study on My Diabetes Coach app among 187 patients with T2DM from Queensland, Victoria and Western Australia which showed a higher reduction in HbA1c and significant improvement in health-related quality of life in the intervention arm compared to the control arm at 12-month post intervention (- 0.33% vs. - 0.2%) [56]. Another study of note is the RCT conducted by Yang et al. on the effectiveness of the Hicare Smart K app for glucose monitoring in primary care involving 247 patients with T2DM [57]. This study showed that the proportions of participants who achieved HbA1c <7% at 3 months were higher (33.8%) in the intervention group vs. the control group (24%) [57]. The intervention group also demonstrated a significant reduction in fasting blood sugar (FBS) compared to the control group (- 19.11mg/dL vs. - 2.41mg/dL) at 3-month post intervention [57]. Another study of note is the RCT conducted by Logan et al. in 2012 involving 110 patients with T2DM in Canada. This study demonstrated that 51% of participants from the intervention group achieved recommended BP target of <130/80 mmHg using the home BP telemonitoring in their self-care group compared to 31% of participants from the control group [36].

Three studies showed no evidence of intervention impact on mobile apps in patients with T2DM. A study by Boels et al. involving 230 patients from the Netherland did not demonstrate any clinically relevant effects when patients were provided with diabetes self-management education and support [58]. Agarwal et al. conducted a study on the BlueStar mobile app among 223 patients in Canada which showed no difference in HbA1c reduction between the intervention (- 0.67%) and the control (- 0.62%) groups [59]. An RCT by Holmen et al. which assessed the effect of the Few Touch app on glycaemic control involving 151 participants in Norway showed no significant difference in mean HbA1c in all groups after 1 year compared to baseline (Few Touch App: 7.8% vs. 8.1%; Few Touch App & health counselling: 8.0% vs. 8.1%; control: 8.2% vs. 8.4%) [60].

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Table 2 The summary of evidence on the effect of mHealth self-management apps for individuals with T2DM

No.	Author and Title	Study Population and Site	Study Design	Tool	Findings
1.	Gong et al. (2020) [56]	187 participants with T2DM, aged between 47 to 67 years; Queensland, Victoria, & Western Australia. Community	Randomised Controlled Trial	My Diabetes Coach [MDC] program (the MDC mobile app, a printed user guide, the MDC website, an optional blood glucose meter with Bluetooth capability and structured interactions with a program coordinator, primarily for technical Assistance	Reduction in HbA1c was found among subjects in the intervention group compared to the control group at 12-month post intervention.
2.	Yang et al. (2020) [57]	247 patients with T2DM, aged 34 to 73 years; Seoul, Korea. Primary Care	Randomised Controlled Trial	Hicare smart K App (mobile app with glucose-monitoring and feedback system for the management of T2DM)	Findings showed participants in the intervention group have significant improvement in HbA1c and FBS compared to the control group at 3-month post intervention.
3.	Cai et al. (2020) [61]	12,530 patients with T2DM, aged between 38 to 75 years; China. Secondary Care	Longitudinal Cohort Study	Mobile health app (APP) education in basal insulin optimal management program for insulin naive T2DM patients	The HbA1c level significantly decreased, and the proportions of participants achieving HbA1c target significantly improved at 3- month and 6-month post intervention.
4.	Lee et al. (2020) [62]	72 patients with T2DM, aged 40 to 62 years; Kangbuk, Korea. Secondary Care	Randomised Controlled Trial	Healthynote Mobile App (mHealth-based diabetes self-management education)	Participants from the intervention group showed statistical improvement in HbA1c and TC at 6-month post intervention.

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5.	Boels et al. (2019) [58]	230 patients aged between 40 to 70 years; Utrecht, Hague & Amsterdam, Netherland. Primary Care	Randomised Controlled Trial	A smartphone app provided information on dietary habits, physical activity, prevention of hypoglycemia, and glucose control (including glycemic variability)	This smartphone app provided diabetes self-management education and support, but no clinically relevant effects were observed.
6.	Koot et al. (2019) [63]	100 patients with T2DM, aged between 21 to 70 years; Tampines, Singapore. Primary Care	Single-Arm Feasibility Study	GlycoLeap Program (Glyco App [mobile lifestyle management app], glucometer, wireless weighing scale, and a resistance band for strength training)	Statistically significant improvements were observed at 24-week post intervention compared to baseline in HbA1c (7.6% vs. 8.9%) and body weight (77.3kg vs. 79.2kg).
7.	Kusnanto et al. (2019) [64]	30 patients with T2DM, aged between 36 to 65 years; North Denpasar, Bali, Indonesia. Primary Care	Randomised Controlled Trial	DM-Calendar App (mobile application as self-management program notification for eating & exercise schedules and blood sugar check)	Significant improvement in HbA1c, TC, triglyceride, HDL-c and LDL-c were found among patients in the intervention group compared to the control group.
8.	Hooshmandja et al. (2019) [65]	51 patients with T2DM, aged 30 to 70 years; Iran. Secondary Care	Quasi-Experimental Study	Mobile learning app on self-care behaviours and blood glucose control	Significant improvement in FBS and HbA1c were observed among participants in the intervention group compared to the control group at 3-month follow-up.
9.	Agarwal et al. (2019) [59]	223 patients aged between 40 to 62 years; Ontario, Canada.	Randomised Controlled Trial	BlueStar mobile app (a virtual coach preloaded onto a cellular network–connected Samsung	A reduction of HbA1c was found in the intervention group compared to the control group at 3-month post intervention.

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		Secondary Care		smartphone connected to a cellular data plan for internet connectivity and was able to connect to local Wi-Fi networks)	
10.	Kleinman et al. (2017) [66]	91 adults with T2DM, aged between 18 to 65 years; Chennai, Mumbai and Ahmedabad, India. Community	Randomised Controlled Trial	Gather App (smartphone app and a Web portal for patients & smartphone app for providers to improve medication adherence and frequency of blood glucose self-testing)	The 6-month mHealth intervention approach showed HbA1c was significantly reduced in the intervention group compared to the control group (1.5% vs. 0.8%).
11.	Fukuoka et al. (2015) [67]	61 obese patients (suspected with T2DM) aged between 36-76 years; San Francisco, USA. Primary Care	Randomised Controlled Trial	Mobile Phone–Based Diabetes Prevention Program [mDPP] (weight-loss mobile app, pedometer, and tailored diabetes prevention program)	The intervention group demonstrated significant reductions in body weight, SBP, DBP and hip circumference compared to the control group at 5-month follow-up.
12.	Holmen et al. (2014) [60]	151 patients aged between 45 to 69 years; Oslo, Norway. Primary Care	Randomised Controlled Trial	Few Touch App (diary mobile app through a wireless Bluetooth connection with a glucometer)	The HbA1c level decreased in all groups but did not differ between groups after 1 year compared to baseline.
13.	Waki et al. (2014) [37]	54 participants with T2DM, aged between 45 to 67 years; Tokyo, Japan.	Randomised Controlled Trial	DialBetics (self-management app includes smartphone with app and wearable devices which paired with a unique	Reductions were found in HbA1c and FBS in the DialBetics group compared to the control group.

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		Community		communicator that transmitted the readings by wireless network to the DialBetics server	
14.	Orsama et al. (2013) [68]	48 participants with T2DM, aged between 30 to 70 years; Sipoo, Finland. Community	Randomised Controlled Trial	Monica App (mobile telephone-based remote patient reporting and automated telephone feedback system)	Significant reductions were observed in HbA1c and body weight in the intervention group compared to the control group at 10-month post intervention.
15.	Logan et al. (2012) [36]	110 participants with T2DM aged between 50 to 72 years; Toronto, Canada. Community	Randomised Controlled Trial	Custom software app running on a blackberry smartphone paired with a Bluetooth-enabled home BP monitoring device	This study found 51% of participants from the intervention group achieved recommended target of <130/80mmHg support using the home BP telemonitoring in their self-care compared to 31% of participants from the control group.
16.	Noh et al. (2010) [69]	44 adult patients with T2DM, aged between 30 to 50 years; South Korea. Secondary Care	Randomised Controlled Trial	eMOD (electronic Management of Diabetes app) via mobile phone and computer	Reductions in HbA1c and postprandial glucose level were found in the intervention group compared to the control group at 6-month post intervention.

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Hypertension

Table 3 summarises the findings of 10 papers of varying study designs on the effect of mHealth apps among individuals with hypertension. Nine papers were RCT and only 1 paper was a non-randomized controlled trial.

Eight out of 10 papers demonstrated significant improvements in the outcomes of interest among patients with hypertension. A study of note is the RCT conducted by Gong et al. on the Yan Fu app among 480 patients with hypertension in China [70]. This study found significant reductions in SBP in the intervention group compared to the control group (- 8.99 mmHg vs. - 5.92 mmHg) and DBP (- 7.04 mmHg vs. - 4.14 mmHg). The intervention group had a greater percentage of patients with controlled BP than the control group (77% vs. 67%) at 1-year post intervention [70]. Another RCT of note is the RCT conducted by Albini et al. which assessed the effect of the Patients Optimal Strategy for Treatment (POST) system, a mobile app in supporting self-management among 601 patients with hypertension in Italy [71]. This study demonstrated that the proportion of patients with controlled BP (<149/90 mmHg) in the intervention group was 72.3% vs. 39.9% in the control group at 6-month follow-up [71].

Two studies showed no evidence of intervention impact of mobile apps in patients with hypertension. A study by Bloss et al. using the HealthyCircle app in 160 patients with hypertension did not show any difference in the mean SBP between baseline and post intervention in both groups [72]. However, greater reduction in the mean DBP was found in the control group (- 6.1mmHg) compared to the intervention group (- 3.6mmHg) at the end of the study [72]. Morawski et al. conducted RCT on the effect of MedISAFE-BP to improve medication adherence and BP control among 411 patients with hypertension in the United States of America [73]. The study showed a small improvement in self-reported medication adherence in the intervention group (0.4%) compared to the control group [73]. However, no change was observed in SBP among participants in the intervention group compared to the control group at 12-week post intervention (- 10.6 mmHg vs. - 10.1mmHg) [73].

Dyslipidaemia

Table 4 shows the only study found on the effect of the mHealth among individuals with dyslipidaemia. This RCT assessed the effect of CHICKEN LOF app among 80 healthcare workers with dyslipidaemia aged between 20 to 55 years old [79]. It reported statistically significant improvements of mean HDL-c in the intervention group compared to the control group [79]. The CHICKEN LOF app group also showed statistically significant reductions in the mean TG, body weight, BMI, body fat percentage, and significant improvement in the basal metabolic rate (BMR) [79]. There were also significant improvements in the knowledge, attitude and practice in the intervention arm compared to the control arm at the end of the study [79].

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Table 3: The summary of evidence on the effect of mHealth self-management apps for individuals with hypertension

No.	Author and Title	Study Population and Site	Study Design	Tool	Findings
1.	Debon et al. (2020) [74]	45 participants with hypertension, aged between 19 to 77 years; Passo Fundo, Rio Grande do Sul, Brazil. Community	Non-Randomized Controlled Trial	e-Lifestyle App (self-management mobile app & monitoring by the health professional via the web)	Significant improvements were found in SBP, FBS, TC, HDL-c and non-HDL-c among participants in the intervention group at 3-month post intervention compared to the control group.
2.	Gong et al. (2020) [70]	480 patients with primary hypertension, aged between 51 to 67 years; Chongqing, China. Secondary Care	Randomised Controlled Trial	"Yan Fu" App (BP management mobile health and Bluetooth-automatic sphygmomanometer)	At 1-year, the intervention group had a greater percentage of patients with controlled BP compared to the control group.
3.	Zha et al. (2019) [75]	25 participants with hypertension aged between 40 to 60 years; Newark, New Jersey. Community	Randomised Controlled Trial	iHealth (iHealth BP7 wireless BP wrist monitor and iHealth MyVitals mobile app)	A significant reduction of SBP was observed in the intervention group at 6-month post intervention compared to the control group.
4.	Chandler et al. (2019) [76]	54 adults with hypertension aged between 21 to 65 years; Charleston, USA. Community	Randomised Controlled Trial	SMASH Program (mobile app with a Bluetooth-enabled BP monitor)	A significant higher number of participants with SBP control in SMASH group compared to the control group at 1-month, 3-month, 6-month and 9-month post intervention.

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5.	Morawski et al. (2018) [73]	411 participants aged between 18 to 75 years; USA. Community	Randomised Controlled Trial	MedISAFE-BP App (medication adherence improvement support app and BP control)	Improvement in self-reported medication adherence was shown but no change in SBP in the intervention group compared to the control group at 12-week post intervention.
6.	Márquez-Contreras et al. (2018) [77]	154 patients with hypertension aged between 48 to 67 years; Huelva, Spain. Primary Care	Randomised Controlled Trial	AlerHTA, App (mobile smartphone to promote hypertension education and reminder of appointments)	A significantly reduced BP was found in the intervention group at 12-month post intervention compared to the control group.
7.	Albini et al. (2016) [71]	601 patients with hypertension aged between 45 to 70 years; Northern Italy. Primary Care	Randomised Controlled Trial	ICT-based Patients Optimal Strategy for Treatment [POST] system (smartphone mobile app [Eurohypertension APP, E-APP], home BP monitoring teletransmission and web-based platform	A stronger BP lowering effect was found in the intervention group compared to the control group at 6-month follow-up.
8.	Bloss et al. (2016) [72]	160 participants with hypertension aged between 45 to 66 years; USA. Community	Randomised Controlled Trial	HealthyCircles mobile app (an iPhone with linked tracking apps paired with a Bluetooth BP monitor blood, glucose meter and AliveCor mobile ECG)	The average SBP did not show any difference between baseline and post intervention in both groups but showed a higher average of DBP dropped in the control group compared to the intervention group.

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9.	Rubinstein et al. (2016) [78]	637 patients with hypertension aged between 30 to 60 years; Buenos Aires (Argentina), Guatemala City (Guatemala) and Lima (Peru). Primary Care	Randomised Controlled Trial	mHealth-based lifestyle intervention app	Reductions in body weight and WC were observed in the intervention group compared to the control group at 12-month post intervention.
10.	Davidson et al. (2015) [33]	38 participants with hypertension aged between 35 to 60 years; Charleston, USA. Community	Randomised Controlled Trial	Smartphone Medication Adherence Stops Hypertension [SMASH] Program (smartphone app with reminder signals, and Bluetooth-enabled monitors)	70.6% of participants in the SMASH group reached BP control (< 140/90 mmHg) compared to the control group with 15.8% at 1-month and 94.4% vs. 41.2% at 6-month post intervention.

Table 4: The summary of evidence on the effect of CHICKEN LOF App among individuals with dyslipidaemia

No.	Author and Title	Study Population and Site	Study Design	Tool	Findings
1.	Puntpanich et al. (2020) [79]	80 health care workers with dyslipidemia, aged between 20 to 55 years; Bangkok, Thailand. Secondary Care	Randomised Controlled Trial	CHICKEN LOF App (mobile health app for lipid profile and body composition)	Statistically significant improvements in the intervention compared to the control groups in mean HDL-c, LDL-c, TG, weight, BMI, body fat percentage and BMR at 3-month post intervention.

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Obesity

Table 5 summarises the findings of 11 papers of varying study designs on the effect of mHealth apps among overweight and obese individuals. Seven papers were RCT, 2 papers were pre-post intervention studies and 2 papers were retrospective cohort studies.

Nine out of 11 papers demonstrated that mHealth apps had an effect in improving outcomes of interest among overweight and obese patients. A study of note is the RCT conducted by Lugones-Sanchez et al. looking at the effect of the combination of EVIDENT 3 app and smart band on body composition among 440 overweight and obese individuals in Spain in 2020. This study demonstrated a greater improvement in the intervention group compared to standard counselling at 3 months with regards to body weight loss (- 1.97 kg vs. - 1.13 kg), body fat mass (1.84 kg vs. 1.11 kg), percentage of body fat (- 1.22% vs. - 0.79%) and BMI (-0.77 kg/m^2 vs. - 0.23 kg/m^2) [80]. Another study of note is the RCT conducted by Partridge et al. in 2016 involving 250 overweight and obese individuals in Spain to assess the effect of mHealth app in improving eating behaviours. Results from this study demonstrated a significant reduction in the mean body weight among participants in the intervention group compared to the control group at 3-month (76kg vs. 78.4kg) and 9-month post intervention (74.9kg vs. 78.4kg) [81].

Two studies showed no evidence of intervention impact of mobile apps in weight management. A study by Ahn et al. showed greater reductions among participants in the paper-based diary group compared to the app group at 6-week post intervention in term of body weight (- 1.4kg vs. - 0.4kg), BMI (- 0.5kg/m^2 vs. - 0.1 kg/m^2), WC (- 2.3cm vs. - 2.2cm) and body fat mass (- 1.3kg vs. - 1.2kg) [82]. Apiñaniz et al. conducted a study on the effect of the AKTIDIET® app to promote a healthy lifestyle in 110 obese and overweight patients in Spain [83]. This study showed greater reductions in the control group compared to the intervention group at 6-month in terms of mean body weight (84.5kg vs. 86.4kg), cholesterol (192.8 mg/dL vs. 195.4 mg/dL), SBP (122mmHg vs. 124.3mmHg) and HbA1c (5.45% vs. 5.55%) [83].

Table 5: The summary of evidence on the effect of mHealth self-management apps for individuals with obesity

No.	Author and Title	Study Population and Site	Study Design	Tool	Findings
1.	Lugones-Sanchez et al. (2020) [80]	440 overweight and obese patients aged between 20 to 65 years; Salamanca, Balear Islands & Valladolid, Spain. Primary Care	Randomised Controlled Trial	EVIDENT 3 App (self-monitoring and tailored feedback smartphone app with smart band to record daily physical activity)	The mHealth intervention showed improvement in body weight, body fat mass, percentage of body fat and BMI compared to the standard counselling at 3-month post intervention.
2.	Ahn et al. (2020) [82]	51 participants aged between 18 to 39 years; Seoul, South Korea. Community	Randomised Controlled Trial	Well-D App (a dietary self-monitoring app)	Greater reductions in body weight, BMI, WC, and body fat mass in the paper-based diary group compared to the app group at 6-week post intervention.
3.	Haas et al. (2019) [84]	43 overweight and obese adults aged between 20 to 67 years; Switzerland. Community	Pre-post Intervention	Oviva App (mobile phone app and registered dietitians to counsel overweight and obese patients)	At 1-year intervention, participants showed significant reductions in body weight, BMI, WC, body fat, SBP and DBP. Overall, 58% of participants achieved a weight loss of $\geq$ 5% from their initial weight at baseline.
4.	Apiñaniz et al. (2019) [83]	110 obese patients aged 18 to 45 years; Spain. Primary Care	Randomised Controlled Trial	AKTIDIET® App (weight loss app including a program for aerobic exercise, muscle training, food intake and reinforced the health advice provided during the consultation)	Greater improvements in weight, cholesterol, SBP and HbA1c were found in the control group compared to the intervention group at 6-month post intervention.

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5.	Mao et al. (2017) [85]	836 overweight and obese participants aged between 32 to 55 years; Wisconsin, Georgia, and Colorado, USA. Community	Retrospective Cohort Study	Vida Health Program (Vida app containing a Bluetooth-connected pedometer and wireless scale)	A total of 218 (28.6%) participants from the intervention group achieved a clinically significant weight loss of ≥ 5% of total body weight compared to an average of 1.81% weight gain in participants in the control group at 4-month.
6.	Partridge et al. (2016) [81]	250 overweight and obese participants aged between 18 to 35 years; Sydney, Australia. Community	Randomised Controlled Trial	TXT2BFiT Program (smartphone app, website, personalised coaching calls with dietitian, text messages and emails)	A significant reduction of body weight in participants from the intervention group compared to the control group at 3-month post intervention.
7.	Hales et al. (2016) [86]	51 overweight and obese adults aged between 32 to 60 years; South Carolina, USA. Community	Randomised Controlled Trial	Social POD App (weight management mobile app)	Participants in the intervention group lost significantly more weight and had a greater reduction in BMI compared to the control group at 3-month post intervention.
8.	Chin et al. (2016) [87]	35,831 overweight and obese participants aged between 30 to 40 years; Korea. Community	Retrospective Cohort Study	Noom Coach Smartphone App (weight loss/reduction mobile app)	77.9% of participants who received the Noom Coach Smartphone App had a decrease in body weight and 22.7% of the participants had > 10% weight loss at 18-month compared to baseline.

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9.	Willey and Walsh (2016) [88]	10 overweight and obese participants aged between 30 to 50 years; St. Louis, USA. Community	Pre-post Intervention	YouPlus Health mobile coaching platform (a mobile phone app-based health with nutritional guidance and fitness program)	Significant reductions were observed in body weight, WC, SBP, DBP and a significant increase was found in HDL-c at 12-week post intervention.
10.	Laing et al. (2014) [89]	82 overweight and obese patients aged between 29 to 58 years; California, USA. Primary Care	Randomised Controlled Trial	Mobile Fitness [mFit] Study (MyFitnessPal, weight management mobile app)	Patients in the intervention group demonstrated weight loss where else, patients in the control group showed weight gain at 3-month and 6-month post intervention.
11.	Carter et al. (2013) [34]	128 overweight and obese participants aged between 30 to 44 years; Leeds, UK. Community	Randomised Controlled Trial	My Meal Mate [MMM] (mobile app for weight loss)	Reductions in weight, BMI and body fat were found in the smartphone app group compared to the diary and website groups at 6-month post intervention.

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DISCUSSION

This review paper summarised current evidence on the effect of mHealth technologies on clinical outcomes and/or self-management behaviours among individuals with MetS or its components. Out of 47 papers, 38 demonstrated effect of mHealth interventions in improving outcomes of interest among individuals with MetS or its components. Nine studies were conducted in secondary care, 12 studies were conducted in primary care and another 26 were conducted in the communities.

With regards to MetS, 7 out 9 papers showed that mHealth self-management interventions had an effect in improving outcomes among individuals with MetS. Some of these studies, however, involved small sample size and short follow-up period. Two of the papers described mHealth apps which provided information to educate and coach users on healthy lifestyle, including nutrition and physical activities [35, 55]. Several of the mHealth apps were equipped with built-in features using sensor or Bluetooth technology such as heart rate monitor, pedometer, glucometer and body weight monitor [35, 48, 52-54]. Apart from mHealth technologies, majority of these studies used other multifaceted elements such as wearable devices, health coaching and web-based programmes [35, 48, 49, 52-55]. These multifaceted approaches could have led to the positive effect of mHealth interventions in improving outcomes among individuals with Met. The 2 studies which have no effect in improving outcomes among individuals with MetS were due to small sample size and short follow-up period [50, 51].

Regarding T2DM, 13 out 16 studies showed that mHealth self-management interventions had an effect in improving outcomes among individuals with T2DM. Two papers described mHealth apps with glucose-monitoring and feedback system [57, 68]. One study with small sample size included notification programme for medication schedules and blood sugar check to improve medication adherence and frequency of blood glucose self-testing [64]. Several mHealth apps included diabetes self-management education and insulin management information [61, 62], wearable devices [37] and glucometer with Bluetooth capability [56, 63]. Two studies with short follow-up period included the use of web portal to monitor self-care data entered by users with the aim to enhance patient-doctor interactions [56, 66]. The 3 studies which have no effect in improving outcomes among individuals with T2DM were due to high dropout rate, undesirable design of the app, low app usage and no monitoring of the app usage [58, 60].

With regards to hypertension, 8 out 10 papers demonstrated that mHealth self-management interventions had an effect in improving outcomes among individuals with hypertension. Two studies showed the positive effect of mHealth intervention which included hypertension education and automated sphygmomanometer to monitor BP using Bluetooth technology [70, 76]. Another 2 studies showed the effect of mobile apps which included features such as reminder signals [33, 77]. Mobile apps which included monitoring of home BP data on web platform by health care providers were also shown to have positive effect although the studies involved short follow-up period [71, 74]. The 2 studies that were not effective in improving outcomes among individuals with hypertension were due to technical issues with the smartphone, bad internet connection and short intervention period [72, 73].

Regarding dyslipidaemia, only 1 study involving small sample size and short follow-up period was retrieved. The CHICKEN LOF mHealth app which promoted healthy lifestyle for individuals with dyslipidaemia was shown to have an effect in improving lipid profile and body composition [79]. This study was conducted in Thailand, a middle-income country, similar to Malaysia.

With the current global obesity epidemic, mHealth technology has emerged as a promising weight-management intervention. Out of 11 studies, 9 showed that mHealth self-management interventions had an effect in improving outcomes among individuals who were overweight or obese despite involving small sample size and short follow-up period. Elements which have been shown to have positive effect in weight loss management included combination of mobile apps with nutritional guidance and fitness programme [88], Bluetooth-connected pedometer and wireless weight scale [85], and smart wrist band to record daily physical activity [80]. Additionally, personalised coaching calls with dietitian, text messages and emails have also been shown to have positive effect in weight loss management [81]. The 2 studies which have no effect in

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improving outcomes among overweight and obese individuals were due to small sample size and short study period [82, 83].

Regarding the use of mHealth technologies among young adults, only 3 studies were found to be targeting this population. One of the studies involved young adults with MetS [52], while another 2 studies involved overweight and obese young adults [81, 87]. All 3 studies showed that mHealth self-management interventions had an effect in improving outcomes among young adults with MetS and those who were overweight and obese.

Strengths and limitations

This narrative review provides a comprehensive summary of the effect of mHealth interventions on individuals with MetS or its components, which covered a great diversity of conditions and outcomes. It also gives instinctive insights and practical information for practising doctors. The search strategy and databases used in this review are also reported. However, we did not use the PRISMA guideline or checklist to review the quality of the papers, as this is not a systematic review. The methodological quality of each study included in this narrative review was not appraised in a structured manner. Several studies included were pilot feasibility studies with small sample size. A robust systematic review and meta-analysis on this topic should be conducted to provide a greater evidence-based source of information.

Another limitation of this narrative review is majority of the studies included were not designed to measure long-term outcome measures such as reduction in CVD events or deaths, as the intervention period was short. A systematic review of evidence which focuses on long-term cohort study or intervention study with long-term follow up period is needed to address this.

Implications for clinical practice and future research

Given the evidence supporting the effect of mHealth interventions among individuals with MetS or its components in this review, its application in clinical practice can be considered. However, only 12 studies were conducted in the primary care settings. Therefore, more research involving mHealth interventions should be done in primary care.

In this review, we also found that the majority of the mHealth self-management apps were developed in the Western countries and high-income Asian countries such as Japan and South Korea. Therefore, these apps might not suit the needs of local population in Malaysia. Thus, there is a need to develop mHealth self-management app which is tailor-made for individuals with MetS and its components in Malaysia. Apart from mHealth technologies which should be used as the main intervention component, multifaceted elements such as doctor-patient interaction, health coaching, wearable devices and complementary web-based tool should also be included. Our research team has developed the EMPOWER-SUSTAIN Self-Management Mobile App© to improve self-management behaviours among patients with MetS in primary care [90].

Future research should include RCT to evaluate the effect of mHealth interventions in Malaysia. More studies involving younger generations should also be conducted.

CONCLUSION

This narrative review suggests that mHealth interventions may have positive effect on clinical outcomes (BP, glycated haemoglobin (HbA1c), lipid profile, weight) and/or self-management behaviours (home BP or blood sugar monitoring, exercise, diet or medication adherence) among individuals with MetS and its components which include T2DM, hypertension, dyslipidaemia, and obesity. This evidence should support development of mHealth intervention to suit the needs of the Malaysian population especially in primary care. Once developed, further research is needed to evaluate the effect of these apps among the target groups, including the younger population.

How does this paper make a difference to clinical practice and future research?

- Apart from mHealth technologies, majority of these studies used other multifaceted elements such as wearable devices, health coaching and web-based programmes.

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- These multifaceted approaches could have led to the positive effect of mHealth self-management interventions in improving outcomes among individuals with Met and its components.
- However, majority of the mHealth self-management apps were developed in the Western countries and high-income Asian countries such as Japan and South Korea.
- Therefore, there is a need to design and develop mHealth self-management intervention which incorporated multifaceted elements such as doctor-patient interaction, health coaching, wearable devices and complementary web-based app for individuals with MetS and its components in Malaysia, especially for the younger generation.
- Future research should include RCT to evaluate the effect of mHealth interventions in Malaysia.

Conflict of Interest

Author declares none.

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Ethical Approval

This narrative review is part of the study protocol which has been approved by the Research Ethics Committee (REC) of Universiti Teknologi MARA [600-IRMI (5/1/6)/REC/134/19].

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Authors' contributions

Maryam Hannah Daud conducted the literature review and prepared the first draft of this manuscript. Anis Safura Ramli and Fakhrul Hazman Yusoff revised the manuscript and provided critical input towards its content. All authors have read and approved the final version of this manuscript.

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