DSX 19 (2025) 103206

Contents lists available at ScienceDirect

Diabetes & Metabolic Syndrome: Clinical Research & Reviews

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

Digital technologies for prediabetes: A systematic review and meta-analysis

Choon Ming Ng, Wing Loong Cheong, Chun Wie Chong, Siew Li Teoh, Wuan Shuen Yap, Shaun Wen Huey Lee *

Monash University Malaysia, School of Pharmacy, Jalan Lagoon Selatan, Bandar Sunway, 47500, Subang Jaya, Selangor, Malaysia

1. Introduction

Prediabetes is a condition characterised by elevated glucose levels that are higher than normal but not high enough to be classified as diabetes [1]. In 2017, it was estimated that 7.3 % of the global population, equivalent to 352 million people were estimated to have prediabetes [2,3]. This figure is projected to rise to 8.3 %, or 587 million people by 2045 [4]. Worryingly, most people who have prediabetes are unaware of the condition [5]. Individuals with prediabetes are at a significant risk of developing type 2 diabetes mellitus (T2DM) along with the severe and life-threatening complications of the disease. For instance, people with prediabetes experience a higher risk of developing chronic kidney disease, neuropathy, diabetic retinopathy, cardiac events, and stroke. Therefore, identifying individuals with prediabetes and subsequently, preventing or delaying the development of diabetes has the potential to significantly reduce mortality, maintain a good quality of life and reduce the burden on the healthcare system [2].

The implementation of lifestyle-changing programs to modify the lifestyle, daily activities, and diet of individuals with prediabetes have been demonstrated to substantially reduce the risk of developing T2DM [6]. For instance, the Diabetes Prevention Programme (DPP) demonstrated that lifestyle intervention reduced the incidence of T2DM by 58 % over an average of 2.8 years [7]. This finding was similarly observed in both the Finnish Diabetes Prevention Study and the Chinese Da Qing Diabetes Prevention Study which concluded that lifestyle changes could prevent T2DM [8,9]. Key objectives in these programmes include achieving a minimum weight loss of 7 % and engaging individuals in moderate-intensity physical activity for a minimum of 150 min every week. While meta-analyses of studies have indicated that lifestyle interventions are effective in preventing or delaying the progression to T2DM, implementing these interventions on a large scale remains challenging [10]. Some key challenges include the difficulty in monitoring the activity and dietary practice of individuals with prediabetes, maintaining high levels of motivation and adherence to the prescribed interventions, as well as the delivery of relevant and timely information [10,11].

One solution to overcome these challenges is through the use of digital technologies - electronic systems designed to provide service remotely which have become increasingly prevalent in healthcare [12,13]. These technologies include telehealth, mobile health (mHealth), game-based support, social platforms, patient portals, as well as wearable devices that collect health data and deliver information [14]. Digital technologies are now used in the monitoring and management of non-communicable diseases including hypertension, T2DM, weight and diet management, as well as to improve medication adherence. The incorporation of digital technologies as remote components has been promising as scalable tools to improve health outcomes as they enhance efficacy, efficiency, accessibility, and allows for personalisation, potentially complementing lifestyle interventions which are often a key challenge in implementation [15]. However, while there is considerable enthusiasm for the innovative role of digital health interventions, the World Health Organization highlighted that it is equally important to generate high-quality evidence and evaluate intervention-contributing effects to ensure that resources are not diverted to ineffective approaches [16]. The lack of comprehensive pooled data from randomised-controlled trials (RCTs) precludes the implementation of digital technologies as an integral digital approach for preventing or delaying diabetes among high-risk groups at a larger scale.

While several reviews on the use of digital technologies have been published, these review only focus on people with type 2 [17,18], type 1 [19,20] and gestational diabetes [21]. To our best knowledge, there are no reviews that attempted to summarise the published research related to the use of different digital technologies and its impact various outcomes for people with prediabetes, with only one review that reported the effects of digital health on weight loss [22]. Another recent review compared the different delivery modality but these do not look into the various digital technologies used [23]. Understanding the effects of different digital technologies are important to guide future policy making and incorporation into routine clinical practice. This systematic review aims to determine the effectiveness of various digital

* Corresponding author.
E-mail addresses: choonming.ng@monash.edu (C.M. Ng), cheong.wingloong@monash.edu (W.L. Cheong), chong.chunwie@monash.edu (C.W. Chong), teoh.siew.li@monash.edu (S.L. Teoh), wsyap8@student.monash.edu (W.S. Yap), shaun.lee@monash.edu (S.W.H. Lee).

https://doi.org/10.1016/j.dsx.2025.103206
Received 3 August 2023; Received in revised form 4 February 2025; Accepted 6 February 2025
Available online 7 February 2025

technologies used in lifestyle interventions for people with prediabetes.

2. Materials and methods

This review was conducted according to the Cochrane Handbook for Systematic Reviews of Interventions and reported according to the Preferred Reporting Items for Systematic Reviews and meta-analyses guideline statement [24]. This study was registered with PROSPERO: CRD42020188051.

2.1. Search strategy

The following databases were searched from database inception to July 31st, 2024: EMBASE, Ovid MEDLINE, Cochrane Central Register of Controlled Trials, AMED and PsychINFO for published articles describing the use of digital technologies among people with prediabetes. The search terms related to digital health and prediabetes were used and included telemedicine, telehealth, prediabetes, impaired fasting glucose, and glucose intolerance. A full list of the search term used can be found in Supplementary File 1. This was supplemented by a hand search of the references of included articles.

2.2. Eligibility criteria

Articles were included if (1) the study examined individuals irrespective of age with prediabetes [25] (defined as having a fasting blood glucose level between 100 and 125 mg/dL or 5.6–6.9 mmol/l, 2-h postprandial glucose between 140 and 199 mg/dL or 7.8–11.0 mmol/l or HbA1c levels between 5.7 and 6.4 %); (2) was a randomised controlled trial; (3) examined the use of digital technology [26] (either telehealth application, mHealth, social platform, game-based support, patient portal, electronic device) for the care of people with prediabetes; and (4) had a control arm. No language restrictions were imposed. Conference proceedings, case studies, reports, editorials, and letters were excluded.

2.3. Data management and selection process

Articles retrieved from the search were compiled using EndNote version 20 (Philadelphia, PA). Any duplicate articles were removed. The list of articles and their abstracts were screened independently by two reviewers for inclusion based on the eligibility criteria detailed above, and any differences were resolved through consensus.

2.4. Data extraction and risk of bias assessment

Two reviewers independently extracted the study demographic data, intervention details, as well as the outcomes of interest using a pre-validated data extraction form. Corresponding author of the articles reviewed were contacted (when necessary) for additional information. The primary outcomes of interest were: 1) changes in body weight; and 2) changes in blood glucose levels [glycated haemoglobin test (HbA1c) and fasting plasma glucose (FPG)]. Other outcomes of interest include body mass index (BMI), waist circumference, biomarkers of cardiovascular diseases including lipid levels (total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), triglyceride), blood pressure as well as the type and amount of physical activity conducted by the study participants. In addition, outcomes on progression to T2DM, quality of life, and cost-effectiveness were also included. Two independent reviewers assessed the risk of bias in all included studies using the Cochrane 2.0 risk-of-bias tool [27].

2.5. Intervention classification

Digital technologies are an umbrella term for electronic systems aimed to provide remote services such as health monitoring, education, and intervention [26]. As defined in past reviews [21,26,28], we categorized studies based on the type of digital technologies used for interventions, which can include telehealth, mHealth, social platform, game-based support, patient portal, and electronic device. The specific definitions for each type of digital technology can be found in Supplementary File 2. Interventions that utilized more than one type of digital technologies were classified as hybrid.

2.6. Statistical analysis

We used the random effects meta-analysis model to pool results and presented them as mean differences (MDs) or odds ratio (OR) with their 95 % confidence intervals (CI) for outcomes. We stratified the analyses based on the types of digital technologies used in the interventions to explore the respective effectiveness. We assessed study heterogeneity using the I^2 statistics. Small study effects were examined using funnel plots. We performed subgroup analysis for each of the primary outcomes by study region (Americas, Asia, Europe and Oceania) as well as intervention study duration (0–11months or 12 months or more). Analyses were conducted using RevMan version 5.4.1 (Cochrane Collaboration, Copenhagen, Denmark). All costs were presented in USD 2021. Any reported costs incurred in other currencies or/and previous years were first converted using purchasing power parities (PPP) or/and inflated using a GDP deflator [29,30].

3. Results

3.1. Selected articles

The initial search identified a total of 480 articles, with 37 articles describing 31 unique studies recruiting a total of 32,624 individuals with prediabetes eligible for inclusion (Fig. 1) [31–67]. Six articles were post hoc analysis papers of included studies [32,48,50,53,54,66]. These studies were conducted in the United States, Germany, the United Kingdom, Canada, Japan, India, Hong Kong, Bangladesh, New Zealand, Singapore, Finland, Saudi Arabia and Thailand. Further details of these studies are summarized in Supplementary File 3.

3.2. Risk of bias

Most included studies had some bias in one of the five domains assessed using RoB 2.0 except for 10 studies. Key limitations were that studies did not report sufficient details on the implementation of study results as well as missing outcome data. Although most trials were not blinded, but these studies were not downgraded due to the nature of the intervention (Fig. 2).

3.3. Intervention assessment

Included studies varied in terms of intervention technology and components used. Several interventions were fully delivered remotely using digital technologies [34,35,37,42,49,51,52,55,57,59–62,67] while others included an in-person components [31,33,36,38–41,43–47,56,58,63–65]. The usual care group received: (1) some form of lifestyle education on T2DM prevention delivered in-person or through paper-based leaflets [34–37,40,42–44,46,47,49,56,57,62,63,65], (2) usual care from healthcare professionals which differed according to practice and may comprise of lifestyle advice and/or education leaflets [33,38,39,41,45,52,55,57–61,67], or (3) non-diabetes related education and was waitlisted [31]. Two studies also provided the control group with online/in-app T2DM prevention modules, but without additional remote education sessions or reinforcements [51,64].

3.4. Digital technologies used

Most studies (n = 17) used a combination of several digital

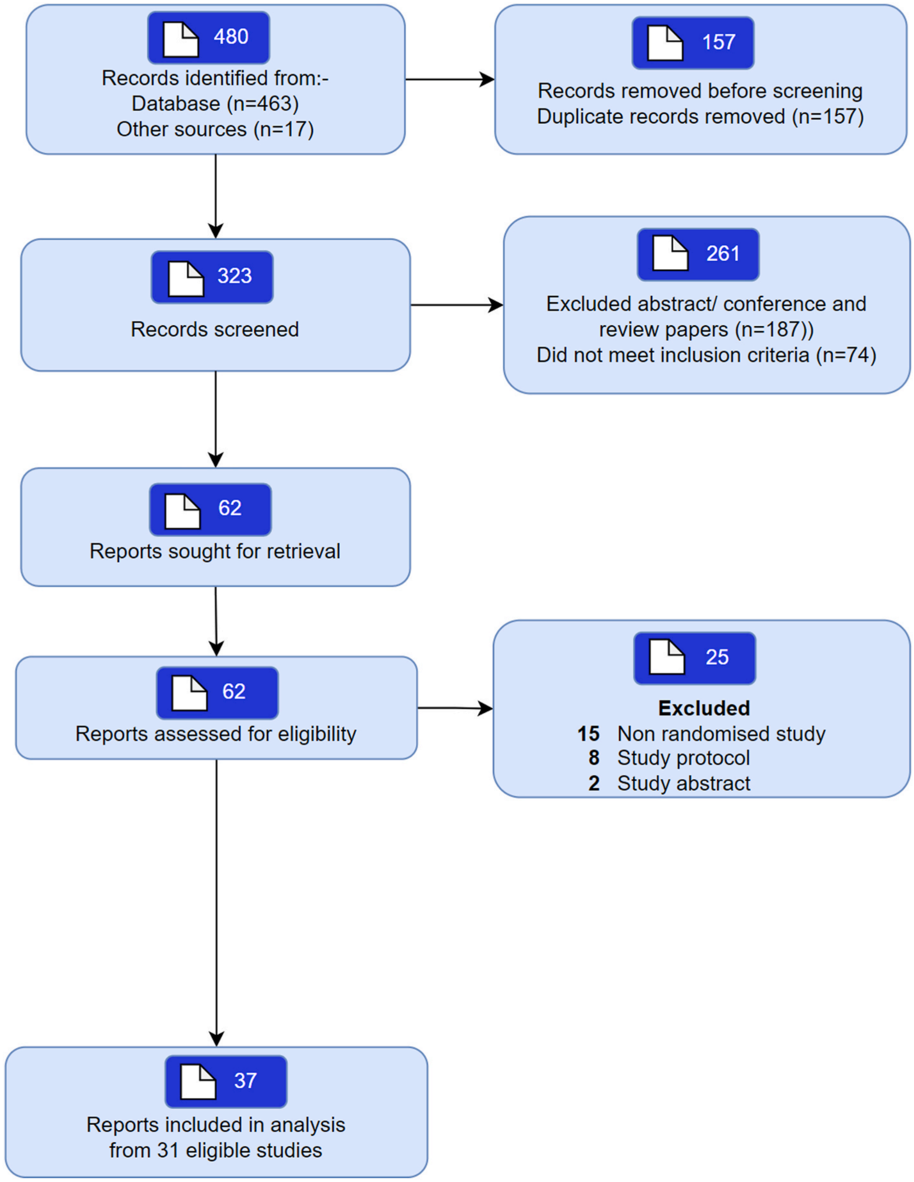

Fig. 1. PRISMA diagram of searching and screening process.

technologies, and were classified as hybrid [31,33–39,41,42,44,45,56,59,61,65,67]. The remaining studies focused on mHealth (n = 9) or telehealth (n = 5) alone. None of the studies used game-based support or patient portals. The details of the delivery methods used in each study are described in Supplementary File 4.

3.4.1. *Telehealth*

Thirteen studies used telephone calls as part of the intervention [33,36–41,43,45,49,56,63,67] to provide motivation, education, coaching, support for behavioural change, consultations, and monitoring in real-time. Telephone calls were most frequently used in combination with monitoring devices, in-person consultations, and hardcopy materials. Apart from phone calls, telehealth was utilized in a telemonitored lifestyle intervention as a communication tool to guide participants throughout the program [35].

3.4.2. *mHealth*

mHealth technologies used were messaging systems (text messages and email) and mobile applications. Text messages were the most commonly used as part of the intervention in eleven studies [33,41,44,46,47,51,52,56,57,62,63]. Emails were only utilized in 3 studies [36,56,67] and at times, used in combination with text messages [33,52]. These messaging systems were mainly used to provide education, motivation, and increase disease awareness. In two of the reviewed studies, text messaging was also integrated into software platforms. The study conducted by Fischer et al. (2016) utilized a patient relationship manager software platform to send messages to selected participants on a pre-determined schedule, as well as to facilitate the screening of incoming participant messages and record participant interactions [41]. In the study conducted by Staite et al. (2019) specific text messages were programmed to be sent to participants based on their level of activity as recorded by their wearable device, as well as on the information recorded by the participants regarding their behaviour into the smartphone application [51].

Mobile applications were utilized for a wide variety of purposes, including recording health behaviours (with or without feedback from a wearable device), goal and routine setting, providing feedback, delivering educational and motivational content, learning reinforcement through quizzes as well as establishing social groups [31,36,42,51,58–61,64,65,67]. In some cases, these were interactive and customised

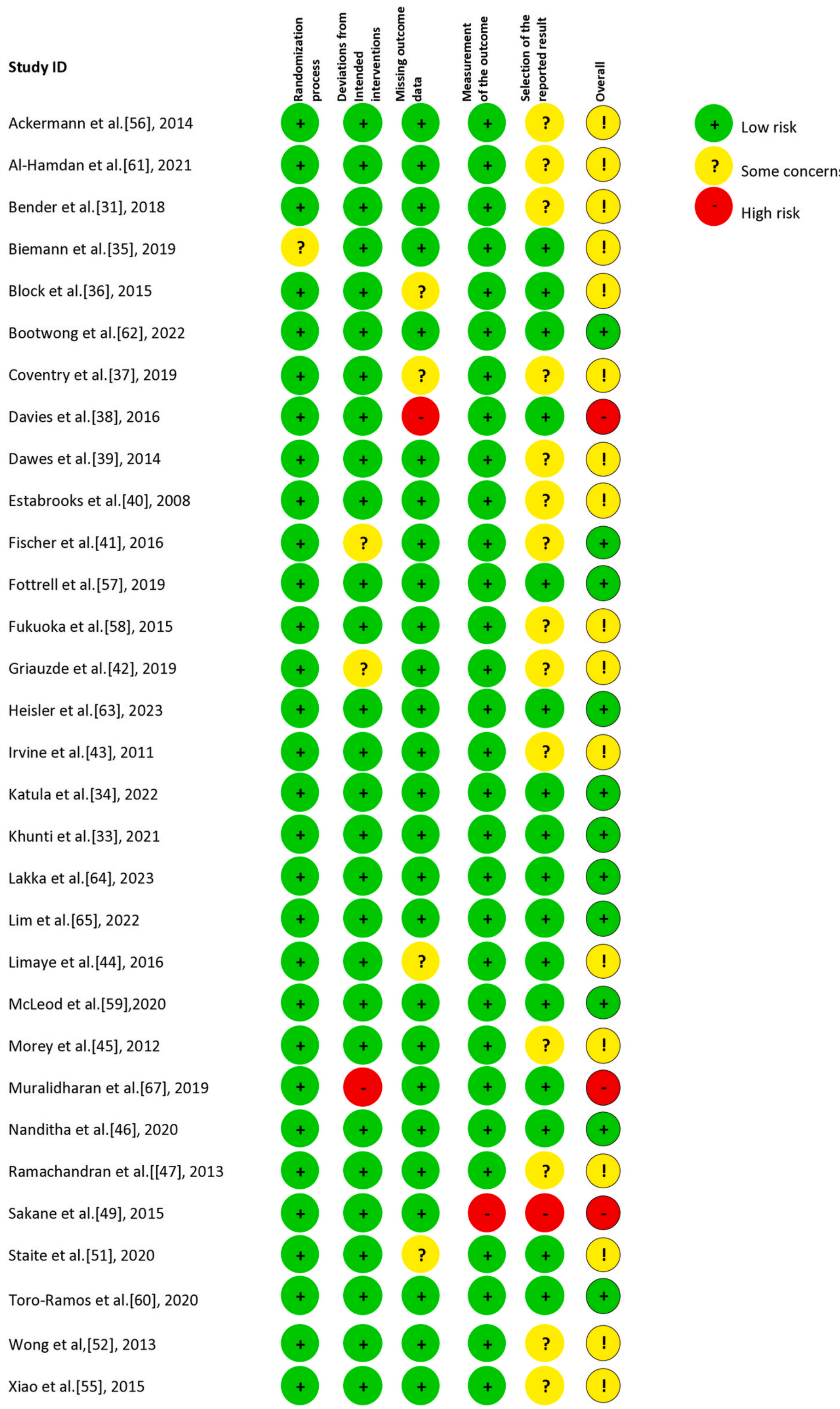

Fig. 2. Risk of bias of included studies.

based on input received from participants, which allowed for the individualised messages to meet the specific needs.

3.4.3. *Social platforms*

Eight studies used social platforms/websites [31,34,36,37,44,56,59,61], which included: (1) social media sites for coaching and peer support, (2) websites that provided educational materials, allowing communications with health advisors and peer support and (3) online platforms that recorded data from wearable devices or data that was input by participants, as well as providing education and feedback. Websites were mostly used in conjunction with mobile applications, devices, text messaging, and other materials.

3.4.4. *Devices*

Ten studies utilized devices as part of the intervention components [31,34,35,37–39,42,45,65,67]. These devices included accelerometers to detect motion and activity, pedometers to track the number of steps taken daily, glucometer for blood glucose monitoring, as well as weighing scales with varying levels of digital capabilities for weight monitoring. Notably, in all the studies, the devices played supportive roles in the intervention to support in monitoring of activities. None of the studies used the devices exclusively as an intervention nor were there any studies where the focus of the intervention was the device used. In addition, some studies used the devices as assessment and/or encouragement tools for both intervention and comparison groups [33,40,43,46,49,51,58,63,65].

3.5. Features of the interventions

The interventions in the studies reviewed provided participants with various content on physical and psychological health, as well as diet. In several studies, participants were also provided with feedback on their performance as well as progress during the intervention.

3.5.1. Healthy eating

Twenty-eight studies provided participants information on nutrition and diet. These included education on the components of a healthy diet and healthy options for meal times, as well as goal setting. Some studies also provided advice on specific diet regimens, while others provided advice on reducing the intake of sugars and fats as well as increasing the intake of fruits and vegetables.

3.5.2. Physical activity

Twenty-nine studies provided participants with some information on how to increase their level of physical activity. This information included advice on goal setting, starting new physical routines, and maintenance of good physical habits. Some studies also provided coaching on how certain types of exercise should be performed.

3.5.3. Psychosocial health

Twenty-five studies addressed the issues of psychological, emotional, mental, and social well-being. The studies provided participants with a mixture of motivational techniques and strategies, as well as advice on stress management, personal development, problem-solving, and building mental resilience. The move was often coupled with social support through the form of peer support and encouragement by the coaching team as well as by other participants in the studies.

3.5.4. Feedback

Eleven studies actively provided feedback to the participants on their progress and achievements during the intervention. The progress included feedback on their reported diet, activity, as well as the achievement of (or failure to achieve) set goals. Feedback was frequently provided either in response to reports or on a regular schedule e.g. weekly or quarterly. The feedback is intended to reinforce positive behaviour and encourage the practice of good habits.

3.5.5. Recording of activities

In several studies, participants were asked to document their health behaviours as part of the intervention and data collection process. This documentation included tracking body weight, physical activity, daily step count and food intake. Physical activity and step count were primarily recorded with wearable devices equipped with accelerometers and pedometers, while food intake was recorded through a combination of logbooks and digital tracking tools.

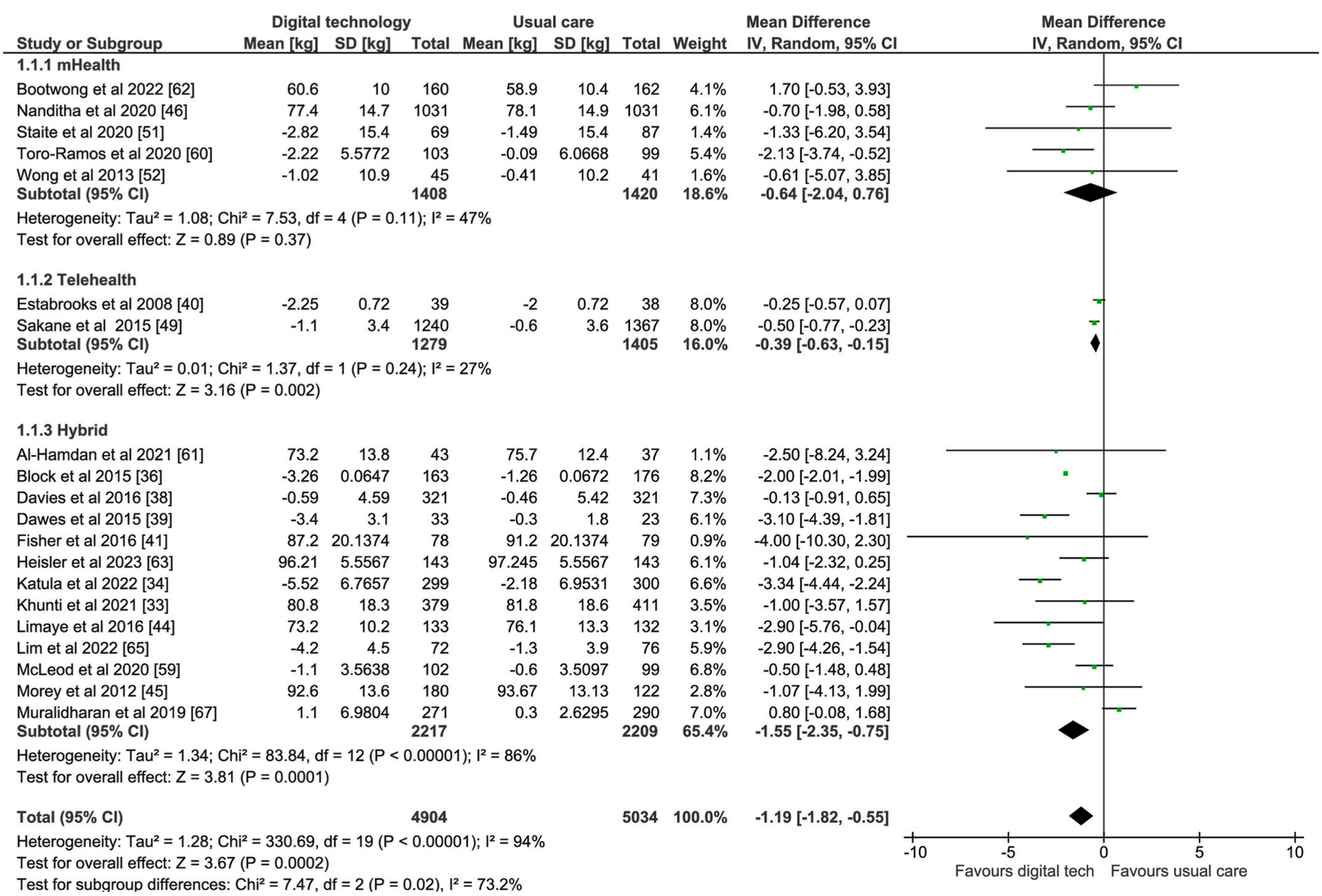

Fig. 3. Pooled effects of digital technology stratified by types on body weight changes at the end of study.

3.6. Outcomes

3.6.1. Anthropometry

Pooled analysis of 20 studies indicated that digital technologies were effective in reducing participants' body weight by 1.19 kg [95 % CI: 1.82 to −0.55] when compared to usual care (Fig. 3, Table 1). Individuals receiving digital technology were found to be twice as likely compared to usual care to achieve a 5 % or more weight loss from baseline (Odds ratio: 2.45, 95 % CI: 1.11 to 5.40, Table 1). Importantly, the use of a combination of digital technologies (hybrid) appeared more beneficial (MD: 1.55 kg; 95 % CI: 2.35 to −0.75) compared to the use of telehealth or mHealth alone.

Similarly, participants randomised to digital technologies reported reduction in the BMIs (−0.74 kg/m^2; 95 % Cl: 0.99 to −0.49, Fig. 4) and waist circumference (MD: 1.63 cm; 95 % Cl: 2.49 to −0.77, Fig. 5).

Table 1
Summary results of meta-analyses of the effects of digital technologies on various outcomes.

Outcome	No. of trials	No. in digital group	No. in control group	Effect size (95 % CI)	I^2 %
Anthropometric outcomes					
Weigh changes at end of study (kg)	20	4904	5034	−1.19 (−1.82 to −0.55)	94
Body mass index (kg/m^2)	14	2952	2945	−0.74 (−0.99 to −0.49)	73
Waist circumference (cm)	12	2760	2764	−1.63 (−2.49 to −0.77)	77
>5 % weight loss at end of study[a]	5	671	701	2.45 (1.11–5.40)	79
>3 % weight loss at end of study[a]	1	78	79	2.29 (1.13–4.61)	–
Weight loss (%)	3	565	575	−3.53 (−5.08 to −1.97)	88
Glucose outcomes					
HbA1c (%)	15	3048	3071	−0.04 (−0.09 to 0.00)	77
Fasting plasma glucose (mmol/L)	8	1984	1924	−0.07 (−0.22 to 0.07)	92
Lipid profile					
Total cholesterol (mmol/l)	11	2696	2688	−0.04 (−0.09 to 0.01)	0
Low density lipoprotein (mmol/l)	3	1143	1157	0.00 (−0.08 to 0.07)	0
High density lipoprotein (mmol/l)	11	2711	2693	0.04 (0.01–0.07)	57
Triglycerides (mmol/l)	11	3962	3928	−0.05 (−0.10 to 0.00)	16
TG/HDL ratio	1	163	176	−0.42 (−0.55 to −0.29)	–
Blood pressure					
Systolic blood pressure (mmHg)	4	285	290	−3.77 (−6.86 to −0.69)	31
Diastolic blood pressure (mmHg)	4	285	290	4.36 (−17.49 to 26.20)	96
Quality of life					
Changes in EQ-5D	3	1414	1464	0.00 (−0.07 to 0.07)	0
SF Physical functioning	3	538	520	−0.07 (−0.19 to 0.05)	0
SF mental well being	2	358	398	0.10 (−0.04 to 0.24)	0
SF-36 general health	2	213	145	−0.04 (−0.25 to 0.17)	0
Other outcomes					
Change in Framingham diabetes risk score from baseline	2	466	543	1.81 (−1.80 to 5.43)	93
Incidence of type 2 diabetes[a]	7	6864	699113	0.94 (0.81–1.09)	48

TG/HDL: triglyceride/high density lipoprotein; SF: Short-form.
[a] Presented as odds ratio with corresponding 95 % confidence interval.

Larger improvements in BMI (MD: 0.87 kg/m^2; 95 % CI: 1.12, −0.62) and waist circumference (MD: 2.56 cm; 95 % CI: 3.41, −1.72) were noted when two or more digital technologies were used compared to only mHealth.

3.6.2. Blood glucose profile

Pooled results found that the use of digital technologies had a limited impact on glycosylated haemoglobin (HbA1c) levels (n = 15 studies; −0.04 %; −0.09 to −0.00) (Supplementary File 5) or fasting plasma glucose (n = 8 studies; −0.07 mmol/L; −0.22 to 0.07, Supplementary File 6).

3.6.3. Lipid profile

Digital technologies had minimal effects in improving lipid parameters including total cholesterol (−0.04 mmol/L; 95 % CI: 0.09 to 0.01), LDL (0.00 mmol/L; 95 % Cl: 0.08 to 0.07), HDL (0.04 mmol/L; 95 % Cl: 0.01 to 0.07) and triglyceride levels (−0.05 mmol/L; 95 % Cl: 0.10 to 0.00) when compared to usual care (Supplementary File 7).

3.6.4. Blood pressure

Five studies reported changes in systolic and diastolic blood pressure at the end of study [35,58,61,62,65]. Pooled analyses suggest that digital technologies can reduce systolic blood pressure marginally by 3.77 mmHg (95 % CI: (−6.86 to −0.69) but not diastolic blood pressure (4.36 mmHg; 95 % CI; −17.49 to 26.20, Table 1).

3.6.5. Physical activity

Interventions that used digital technologies showed improvements in objectively-measured outcomes such as steps count per day [33,38,58], exercise endurance level [39], moderate physical activity level [58], time spent in moderate-to-vigorous activity, and time spent walking [33]. In addition, self-reported data demonstrated favourable outcomes in sedentary time [38], leisure time activity [39], time spent in physical activity [65] and physical activity energy (METs)/min/week [62]. Other studies reported minimal effect on steps count/day, time spent in physical activity, sedentary time [51,63,64] while Khunti et al. (2021) found that improvement in physical activity was not sustained.

3.6.6. Incidence of type 2 diabetes mellitus

Seven studies including 13857 reported the incidence of type 2 diabetes after 6–48 months of follow up were analysed. At the end of latest follow-up, individuals in the intervention group had a lower odds of progressing to type 2 diabetes mellitus (Odds ratio: 0.94; 95%CI: 0.81 to 1.09, Table 1) when compared to usual care [35,38,46,47,49,52,57].

3.6.7. Cost and cost-effectiveness analyses

Seven studies reported cost-related results (Table 2). The results varied widely between studies due to differences in the measurement and reporting of cost-related outcomes. Fottrell et al. (2019) suggested that the intervention used was highly cost-effective while Wong et al. (2013) suggested that there may be some reduction in costs when compared to standard care [52,57]. Khunti et al. (2021), however, reported the interventions had lower probabilities of being cost-effective [33].

3.6.8. Quality of life

Seven studies including 4170 individuals reported quality-of-life outcomes using EuroQoL-5D (EQ-5D), Short Form-36 or 15-dimensoional questionnaire (Table 3) [33,37–39,45,46,53]. Follow-up time varied between 6 months and 4 years. Most studies reported no significant difference in the quality of life while only two other studies reported a significant increase in the quality-of-life post-intervention [38,53]. Pooled analyses showed no difference for EQ-5D, Short-Form (SF) Physical function, SF mental well-being and SF-36 general health scores.

Study or Subgroup	Digital technology Mean [kg/m2]	SD [kg/m2]	Total	Usual care Mean [kg/m2]	SD [kg/m2]	Total	Weight	Mean Difference IV, Random, 95% CI
1.2.1 mHealth								
Bootwong et al 2022 [62]	24.2	3.9	160	23.7	3.9	162	5.4%	0.50 [-0.35, 1.35]
Nanditha et al 2020 [46]	28.2	4.4	1031	28.3	4.6	1031	10.8%	-0.10 [-0.49, 0.29]
Ramachandran et al 2013 [47]	25	5.5	271	25	5.4	266	4.9%	0.00 [-0.92, 0.92]
Toro-Ramos et al 2020 [60]	-1.79	2.8142	103	-0.04	2.156	99	6.9%	-1.75 [-2.44, -1.06]
Wong et al 2013 [52]	25.14	3.33	45	25.97	3.08	41	2.8%	-0.83 [-2.18, 0.52]
Subtotal (95% CI)			**1610**			**1599**	**30.8%**	**-0.43 [-1.22, 0.37]**
Heterogeneity: Tau² = 0.64; Chi² = 22.28, df = 4 (P = 0.0002); I² = 82%								
Test for overall effect: Z = 1.05 (P = 0.29)								
1.2.2 Hybrid								
Al-Hamdan et al 2021 [61]	29.4	5.1	43	31.5	5.7	37	1.0%	-2.10 [-4.49, 0.29]
Block et al 2015 [36]	-1.05	0.0647	163	-0.39	0.0672	176	14.5%	-0.66 [-0.67, -0.65]
Coventry et al 2019 [37]	32.4	0.73	84	33.8	6.7	89	2.6%	-1.40 [-2.80, 0.00]
Davies et al 2016 [38]	31.83	1.66	321	32.93	1.77	321	12.5%	-1.10 [-1.37, -0.83]
Dawes et al 2015 [39]	-1.2	1.1	33	0	0.7	23	9.6%	-1.20 [-1.67, -0.73]
Khunti et al 2021 [33]	28.6	5.1	313	29.2	6	370	5.6%	-0.60 [-1.43, 0.23]
Limaye et al 2016 [44]	26.6	3.2	133	27.6	3.6	132	5.7%	-1.00 [-1.82, -0.18]
Lim et al 2022 [65]	-1.5	1.7	72	-0.5	1.5	76	9.0%	-1.00 [-1.52, -0.48]
Morey et al 2012 [45]	-0.61	2.35	180	-0.33	2.35	122	8.7%	-0.28 [-0.82, 0.26]
Subtotal (95% CI)			**1342**			**1346**	**69.2%**	**-0.87 [-1.12, -0.62]**
Heterogeneity: Tau² = 0.06; Chi² = 22.22, df = 8 (P = 0.005); I² = 64%								
Test for overall effect: Z = 6.85 (P < 0.00001)								
Total (95% CI)			**2952**			**2945**	**100.0%**	**-0.74 [-0.99, -0.49]**
Heterogeneity: Tau² = 0.11; Chi² = 48.99, df = 13 (P < 0.00001); I² = 73%								
Test for overall effect: Z = 5.75 (P < 0.00001)								
Test for subgroup differences: Chi² = 1.09, df = 1 (P = 0.30), I² = 8.4%								

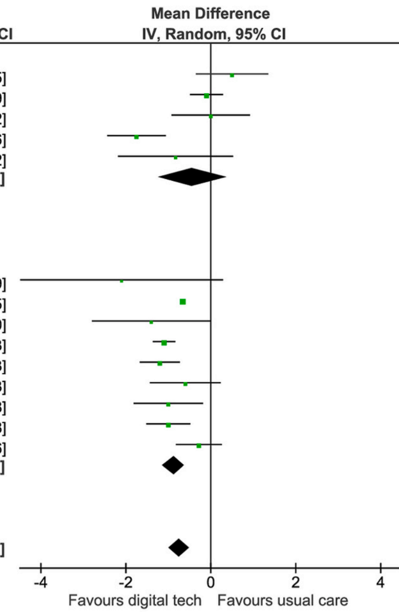

Fig. 4. Pooled effects of digital technology stratified by types on body mass index.

Study or Subgroup	Digital technology Mean [cm]	SD [cm]	Total	Usual care Mean [cm]	SD [cm]	Total	Weight	Mean Difference IV, Random, 95% CI
1.3.1 mHealth								
Bootwong et al 2022 [62]	82.5	8.2	160	82.2	9.1	162	8.7%	0.30 [-1.59, 2.19]
Lakka et al 2023 [64]	0	0	0	0	0	0		Not estimable
Nanditha et al 2020 [46]	96.2	10.7	1031	96.7	10.9	1031	12.8%	-0.50 [-1.43, 0.43]
Ramachandran et al 2013 [47]	92.6	7.9	271	92.6	7.7	266	11.1%	0.00 [-1.32, 1.32]
Staite et al 2020 [51]	96.73	11.7	69	97.38	11	86	4.1%	-0.65 [-4.26, 2.96]
Wong et al 2013 [52]	90.82	8.18	45	92.95	7.85	41	4.5%	-2.13 [-5.52, 1.26]
Subtotal (95% CI)			**1576**			**1586**	**41.3%**	**-0.34 [-1.01, 0.34]**
Heterogeneity: Tau² = 0.00; Chi² = 1.91, df = 4 (P = 0.75); I² = 0%								
Test for overall effect: Z = 0.97 (P = 0.33)								
1.3.2 Hybrid								
Al-Hamdan et al 2021 [61]	88.8	12.3	43	93.4	10.3	37	2.5%	-4.60 [-9.55, 0.35]
Block et al 2015 [36]	-4.56	0.8405	163	-2.22	0.9411	176	15.0%	-2.34 [-2.53, -2.15]
Davies et al 2016 [38]	104.37	5.8	320	108.17	6.32	320	12.8%	-3.80 [-4.74, -2.86]
Dawes et al 2015 [39]	-4	5	33	-1	5	23	6.2%	-3.00 [-5.66, -0.34]
Khunti et al 2021 [33]	99.5	13.8	312	100.6	14.7	368	7.8%	-1.10 [-3.24, 1.04]
Limaye et al 2016 [44]	93.9	7.5	133	96.6	9.6	132	8.0%	-2.70 [-4.78, -0.62]
Morey et al 2012 [45]	103.92	10	180	104.43	11.7	122	6.5%	-0.51 [-3.05, 2.03]
Subtotal (95% CI)			**1184**			**1178**	**58.7%**	**-2.56 [-3.41, -1.72]**
Heterogeneity: Tau² = 0.53; Chi² = 13.46, df = 6 (P = 0.04); I² = 55%								
Test for overall effect: Z = 5.94 (P < 0.00001)								
Total (95% CI)			**2760**			**2764**	**100.0%**	**-1.63 [-2.49, -0.77]**
Heterogeneity: Tau² = 1.28; Chi² = 48.02, df = 11 (P < 0.00001); I² = 77%								
Test for overall effect: Z = 3.72 (P = 0.0002)								
Test for subgroup differences: Chi² = 16.21, df = 1 (P < 0.0001), I² = 93.8%								

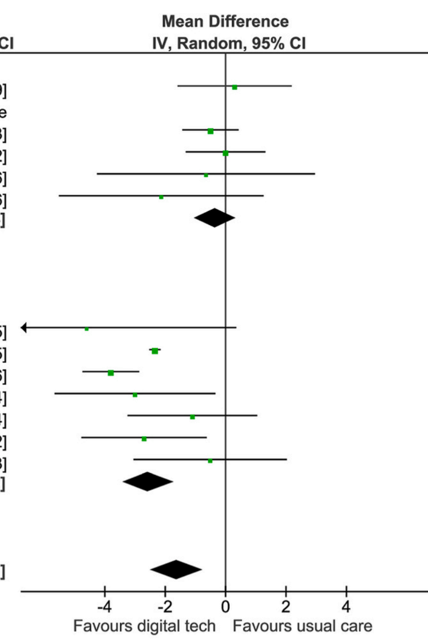

Fig. 5. Pooled effects of digital technology stratified by types on waist circumference.

3.7. Subgroup analyses

Subgroup analyses of primary outcomes by study region showed that studies conducted in the Americas region had better weight changes and HbA1c outcomes compared to other regions. Similarly, studies that were conducted at least 12 months or longer resulted in significant changes in weight loss compared to studies that were of shorter duration.

4. Discussion

The present systematic review and meta-analysis showed that lifestyle interventions delivered using digital technologies were effective in reducing body weight, BMI, and waist circumference outcomes in comparison to the usual care group. When these interventions incorporated more than one type of digital technology, this appeared to be more beneficial compared to when mHealth or telehealth was used alone. These results are very encouraging as weight loss is the cornerstone for the reduction and delay in T2DM incidence among people with prediabetes [68–70]. However, pooled analysed did not demonstrate any effects in improving HbA1c, fasting blood glucose and lipid levels when compared to usual care.

Interventions that can successfully prevent people with prediabetes from developing T2DM can have a major impact on public health [71]. As such, there have been attempts to implement lifestyle interventions and community programs that delay/prevent the development of T2DM and its complications. A recent systematic review and meta-analysis elucidated that lifestyle interventions focusing on the change in physical activity and diet are safe, clinically effective, and cost-effective for

Table 2
Cost and cost-effectiveness outcomes reported in studies.

Study	Cost Details	Perspective	USD 2021 (95 % CI)	Interpretation
Irvine 2011	Direct medical cost comparing the ICER per QALY (compared to usual care)	Healthcare and limited societal	16,693 (NA)	Not cost-effective (only 16 % probability that intervention is cost-effective)
Wong 2013[a]	Direct medical cost comparing the cost reduction for each subject with 5.05 % of T2DM onset compared to usual practice	Healthcare	237 (NA)	Cost-saving
Fischer 2016	Total annual program direct medical cost	Healthcare	92,877 (NA)[b]	NA
Limaye 2016	Direct incremental medical cost of treating/ preventing one case of overweight/ obesity in 1 year	Healthcare	2314 (NA)[b]	NA
Coventry 2019	Direct incremental medical cost per point improvement on outcome (CSQ-8)	Healthcare	42 (19–213)	NA
Fottrell 2019	Direct incremental cost-effectiveness ratios per case of T2DM prevented among individuals with intermediate hyperglycaemia at baseline.	Healthcare	11,407 (NA)	Highly cost-effective (according to WHO cost-effectiveness threshold)
	Direct incremental cost-effectiveness ratios per DALY averted among individuals with intermediate hyperglycaemia at baseline.	Healthcare	4464 (NA)	Highly cost-effective (according to WHO cost-effectiveness threshold)
Khunti 2021	Direct medical costs were used for both model-based evaluation and within trial analysis	Healthcare and limited societal	2600-2609 (interventions) compared to 2561 (usual care) (NA)[c]	The probabilistic lifetime costs of interventions remained higher than those for usual care at a threshold of USD 2021 2267 per QALY

CI, Confidence interval; CSQ-8, Client satisfaction questionnaire-8; DALY, Disability-adjusted life-year; ICER, Incremental cost-effectiveness ratio; NA, not applicable; T2DM, Type 2 diabetes mellitus; QALY, Quality-adjusted life-year; WHO, World Health Organization.
[a] Values reported by Wong 2015.
[b] Not clearly reported, value was estimated by the reviewer.
[c] GBP 2017 was taken as the original currency year and was reported to be GBP 2017/2018.

Table 3
Quality of life outcomes reported by each study.

Study	QoL Measurement	Results
Morey 2012	SF-36	No significant difference between I and C
Wong 2013[a]	QALY	Higher 0.063 life years and 0.071 QALYs gained in I compared to C
Dawes 2014	EQ-5D and SF-36	No significant differences[b]
Davies 2016	15-D	Significant increase betwee [1,2]n I and C at 36 months (0.02 (95 % CI: 0.01, 0.03), $p < 0.01$) but not between 6 and 24 months
Coventry 2019	EQ-5D-5L and EQ VAS	No significant difference between I and C
Nanditha 2020	EQ-5D-3L	No significant difference[b]
Khunti 2021	EQ-5D-5L and SF-8	No significant differences[b]

15-D, 15-Dimensional; C, Comparator; EQ-5D, EuroQol-5 Dimensions; I, Intervention; SF-36, 36-Item Short Form Health Survey; SF-8, 8-item Short Form Health Survey; QALY, Quality-adjusted life-year; QOL, Quality of life; VAS, visual analogue scale.
[a] Values reported in Wong 2015.
[b] Comparison not stated for statistical significance analysis.

preventing or delaying the progression of T2DM [72]. The implementation of these programs, however, can be challenging, and the integration of digital technologies may help overcome some of the hurdles faced. Thus, this review provided timely and important insights into the present and future use of digital technologies for individuals with prediabetes by highlighting the effectiveness of currently available evidence and areas for further improvements.

We noted from the studies reviewed that interventions utilizing digital technologies are considered complex interventions where there is no one single element that contributed most to the pooled-effect sizes. This is a common finding among other reviews of digital technologies used in lifestyle interventions for healthcare [21]. This may partially reflect the complex health needs of people with prediabetes along with the complexities related to the intervention. In line with the studies reviewed, interventions delivered using digital technologies typically consist of various active components including the provision of education, behaviour change support, communications with healthcare professionals, self-tracking, and monitoring [73]. While we attempted to explore the respective effectiveness of various types of digital technologies by stratifying our analyses, the number of studies for each category remained small, limiting further comparison. The diverse combination of digital technologies used in the studies reviewed has also made it more difficult to identify and outline the contribution of these technologies to the beneficial effects observed. As a start, we found that using several types of digital technologies which may include a combination of mHealth, telehealth, social platforms, and devices appeared slightly more beneficial than the use of one specific category of digital technology (mHealth or telehealth alone).

One of the objectives of this review was to determine whether lifestyle interventions using digital technologies were effective in reducing the risk of developing T2DM among people with prediabetes. The review and meta-analysis conducted on the included studies suggest that these interventions may be beneficial, although the magnitude of the effect remains unclear. Only seven of the 31 studies reviewed specifically investigated the incidence of T2DM among the study population, and while the results of the studies indicated that the groups receiving the interventions had lower prevalence or lower incidence of T2DM when compared to the control group, the observed differences were often not statistically significant. As such, we had to consider the impact of these interventions on the risk factors of developing T2DM such as body weight, BMI, waist circumference, blood glucose, and lipid levels in our analyses.

Overall, our findings reinforced that lifestyle interventions are effective in improving the health of individuals with prediabetes [8–10]. Our study further extends the current knowledge base in literature by showing the potential use of digital technologies in reducing the risk factors associated with the development of T2DM, particularly in anthropometry outcomes. The usage of digital technologies was instrumental for the frequent and regular data collection, communication of education and information, and maintaining motivation in the studies reviewed. The data suggest that at a minimum, similar programs utilizing digital technologies to overcome the usual barriers of information collection, intervention delivery and adherence, can help improve health and reduce the risk of developing T2DM.

While the improvement of health should contribute to a better quality of life, the interventions in the studies reviewed did not appear to have much of an impact on quality of life. It is unclear, however, whether this is due to an actual lack of impact or due to the lack of an appropriate quality-of-life questionnaire or measurement instrument for people with prediabetes. Discussions on incorporating digital technologies often touch on the issue of cost-effectiveness and whether the use of these technologies will result in an unsustainable or infeasible incremental cost to either healthcare providers or patients. The studies in this review, unfortunately, did not provide conclusive evidence on the cost-effectiveness of the interventions, which suggests that subsequent studies using digital technologies in lifestyle interventions to prevent T2DM should include full economic evaluations. The wider implementation of these interventions will also have to consider the targeted community's ability to afford the devices used, as these can vary widely [74].

4.1. Limitations

There are some limitations to this review that needs to be acknowledged. Firstly, we did not have access to individual participants' data and thus the effects of potential confounders including digital literacy could not be ruled out. Secondly, most of the trials included were exploratory in nature and included a wide variety of digital technologies ranging from telephone calls to digital devices, making specific comparisons between intervention types challenging. Another limitation is the small number of studies. Despite the extensive search, only 31 unique studies were identified. The studies were also predominantly conducted in high-income countries, which suggests that additional studies that address the acceptability, feasibility, and implementation of these interventions in low-income and middle-income countries are required.

The studies reviewed also varied in terms of methodological aspects including intervention intensity, duration of follow-up, and the outcomes measured. Many of the studies reviewed reported a wide variety of outcomes, ranging from metabolic and glucose parameters, anthropometrics, as well as patient-reported outcomes such as quality of life. For example, several studies had only reported on glucose parameters while others included blood pressure and even cost analysis. The differences across studies may partially explain the large heterogeneity seen in this study. Most of these studies were also assessed in isolation, and often do not reflect the usual clinical practice. Besides, some of the studies had some concerns of bias based on our assessment. Poor reporting was a common issue as most studies had not reported on missing data, which limits the conclusions that could be drawn. Finally, most of the included studies had a small sample size and lacked clearly defined primary outcomes, which may result in false positive results. Nevertheless, the study design, study question, eligibility criteria, description of intervention, and the definition of the study outcomes were found to be adequate in most of the studies included.

4.2. Clinical relevance

With the current global burden of T2DM, countries worldwide must take effective preventive action. Along with the growing interest in digital technologies attributed to increasing affordability and the prospects for universal health coverage, our findings are timely and relevant for the prevention of T2DM among high-risk groups. Overall, the review contributes to advancement in the management of prediabetes through the use of digital technologies for greater diabetes prevention outreach. Nonetheless, further evaluations into digital technologies are needed to support people with prediabetes. This should ideally be conducted using an adequately powered RCT, with appropriate outcomes as study endpoints. Beyond that, further research on implementation is needed to understand the feasibility and acceptability in a diverse community and setting. These ideally should leverage on real-world data which can be used to inform the acceptability in clinical practice. Finally, it would also be important to explore the possible impact on behavioural changes at various time points, such as adherence to lifestyle advice and physical activity.

5. Conclusion

The evidence, to date, suggests that lifestyle interventions incorporating digital technologies can be effective in helping people with prediabetes reduce their body weight, BMI, and waist circumference. The effectiveness of these interventions in improving blood glucose, lipid profile, blood pressure, physical activity, and quality of life remains unclear. While the results are encouraging, more work is required to improve the evaluation and implementation of these complex interventions.

Availability of data and material

The study used publicly accessible data obtained through scholarly search engines.

CRediT authorship contribution statement

Ng Choon Ming: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. Wing Loong Cheong: Data curation, Investigation, Methodology, Validation, Writing - review & editing. Chun Wie Chong: Methodology, Validation, Funding acquisition. Siew Li Teoh: Conceptualization, validation, Writing - original draft. Wuan Shuen Yap: Project administration, Validation, Visualization, Writing - review & editing. Shaun Wen Huey Lee: Conceptualization, Funding acquisition, Supervision, Validation, Visualization. Writing - original draft, Writing - review & editing.

Funding

The study was supported by Monash University's Network for Equity through Digital Health (NEED) initiative (Project code: PHA/NEED/11–2020/001). The funder had no role in the study design.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dsx.2025.103206.

References

[1] Bansal N. Prediabetes diagnosis and treatment: a review. World J Diabetes 2015;6 (2):296–303.
[2] Mutie PM, Pomares-Millan H, Atabaki-Pasdar N, et al. An investigation of causal relationships between prediabetes and vascular complications. Nat Commun 2020; 11(1):4592.
[3] Hostalek U. Global epidemiology of prediabetes - present and future perspectives. Clin Diabetes Endocrinol 2019;5:5.
[4] Federation ID, editor. IDF diabetes atlas. eighth ed. Brussels: International Diabetes Federation; 2017.
[5] Diabetes report card 2019. Atlanta: Centers for Disease Control and Prevention; 2020.
[6] Tuso P. Prediabetes and lifestyle modification: time to prevent a preventable disease. Perm J 2014;18(3):88–93.
[7] Knowler WC, Barrett-Connor E, Fowler SE, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002 Feb 7;346 (6):393–403.
[8] Pan X-R, Li G-W, Hu Y-H, et al. Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance: the da qing IGT and diabetes study. Diabetes Care 1997;20(4):537.
[9] Tuomilehto J, Lindström J, Eriksson JG, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med 2001;344(18):1343–50.
[10] Howells L, Musaddaq B, McKay AJ, et al. Clinical impact of lifestyle interventions for the prevention of diabetes: an overview of systematic reviews. BMJ Open 2016; 6(12):e013806.
[11] Subramanian K, Midha I, Chellapilla V. Overcoming the challenges in implementing type 2 diabetes mellitus prevention programs can decrease the burden on healthcare costs in the United States. J Diabetes Res 2017;2017: 2615681.
[12] Oldenburg B, Taylor CB, O'Neil A, et al. Using new technologies to improve the prevention and management of chronic conditions in populations. Annu Rev Publ Health 2015;36(1):483–505.
[13] Lee SWH, Chan CKY, Chua SS, et al. Comparative effectiveness of telemedicine strategies on type 2 diabetes management: a systematic review and network meta-analysis. Sci Rep 2017 Oct 4;7(1):12680.
[14] Shan R, Sarkar S, Martin SS. Digital health technology and mobile devices for the management of diabetes mellitus: state of the art. Diabetologia 2019;62(6): 877–87.
[15] Gentilini L, De Remigis A, Rubbi I, et al. Distal technologies impact, telehealth and mhealth, on type 1 diabetes self-management: a narrative review. Curr Res Diabetes; Obesity J 2019;11(5):1–10.
[16] World Health Organization. WHO guideline recommendations on digital interventions for health system strengthening. 2019. Geneva.
[17] Moschonis G, Siopis G, Jung J, et al. Effectiveness, reach, uptake, and feasibility of digital health interventions for adults with type 2 diabetes: a systematic review and meta-analysis of randomised controlled trials. The Lancet Digital Health 2023;5(3): e125–43.
[18] Ossenbrink L, Haase T, Timpel P, et al. Effectiveness of digital health interventions containing game components for the self-management of type 2 diabetes: systematic review. JMIR Serious Games 2023 Jun 1;11:e44132.
[19] Garner K, Boggiss A, Jefferies C, et al. Digital health interventions for improving mental health outcomes and wellbeing for youth with type 1 diabetes: a systematic review. Pediatr Diabetes 2022;23(2):258–69.
[20] Lee SWH, Ooi L, Lai YK. Telemedicine for the management of glycemic control and clinical outcomes of type 1 diabetes mellitus: a systematic review and meta-analysis of randomized controlled studies. Front Pharmacol 2017;8:330.
[21] Leblalta B, Kebaili H, Sim R, et al. Digital health interventions for gestational diabetes mellitus: a systematic review and meta-analysis of randomised controlled trials. PLOS Digital Health 2022;1(2):e0000015.
[22] Fredensborg Holm T, Udsen FW, Giese IE, et al. The effectiveness of digital health lifestyle interventions on weight loss in people with prediabetes: a systematic review, meta-analysis, and meta-regression. J Diabetes Sci Technol 2024 Nov;7: 19322968241292646.
[23] Smith EA, Hubbard SJ, Freeman SC, et al. The effectiveness of delivery modalities of non-pharmacological diabetes prevention programs: a systematic review and component network meta-analysis. Diabetes Metabol Syndr: Clin Res Rev 2024;18 (10):103136. 2024/10/01/.
[24] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
[25] American Diabetes Association. Diagnosis and classification of diabetes mellitus. Diabetes Care 2013;37(Supplement_1):S81–90.
[26] Duke DC, Barry S, Wagner DV, et al. Distal technologies and type 1 diabetes management. Lancet Diabetes Endocrinol 2018 Feb;6(2):143–56.
[27] Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.
[28] Chakranon P, Lai YK, Tang YW, et al. Distal technology interventions in people with diabetes: an umbrella review of multiple health outcomes. Diabet Med 2020; 37(12):1966–76.
[29] [Internet] PPP conversion factor, GDP (LCU per international $). The World Bank; 2022 [cited 1 December 2022]. Available from: https://data.worldbank.org/indicator/PA.NUS.PPP.
[30] Inflation. GDP deflator (annual %) [Internet]. The World Bank; 2022 [cited 1 December 2022], https://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG.
[31] Bender MS, Cooper BA, Flowers E, et al. Filipinos Fit and Trim - a feasible and efficacious DPP-based intervention trial. Contemporary Clin Trials Commun 2018; 12:76–84.
[32] Sakane N, Oshima Y, Kotani K, et al. Impact of telephone support programme using telemonitoring on stage of change towards healthy eating and active exercise in people with prediabetes. J Telemed Telecare 2021;27(5):307–13.
[33] Khunti K, Griffin S, Brennan A, et al. Behavioural interventions to promote physical activity in a multiethnic population at high risk of diabetes: PROPELS three-arm RCT. Health Technol Assess 2021 Dec;25(77):1–190.
[34] Katula JA, Dressler EV, Kittel CA, et al. Effects of a digital diabetes prevention program: an RCT. Am J Prev Med 2022 Apr;62(4):567–77.
[35] Biemann R, Penner M, Borucki K, et al. Serum bile acids and GLP-1 decrease following telemetric induced weight loss: results of a randomized controlled trial. Sci Rep 2016;6(1):30173.
[36] Block G, Azar KMJ, Romanelli RJ, et al. Diabetes prevention and weight loss with a fully automated behavioral intervention by email, web, and mobile phone: a randomized controlled trial among persons with prediabetes. J Med Internet Res 2015;17(10):e240.
[37] Coventry P, Bower P, Blakemore A, et al. Satisfaction with a digitally-enabled telephone health coaching intervention for people with non-diabetic hyperglycaemia. npj Digital Med 2019;2(1):5.
[38] Davies MJ, Gray LJ, Troughton J, et al. A community based primary prevention programme for type 2 diabetes integrating identification and lifestyle intervention for prevention: the Let's Prevent Diabetes cluster randomised controlled trial. Prev Med 2016;84:48–56.
[39] Dawes D, Ashe M, Campbell K, et al. Preventing diabetes in primary care: a feasibility cluster randomized trial. Can J Diabetes 2015;39(2):111–6.
[40] Estabrooks PA, Smith-Ray RL. Piloting a behavioral intervention delivered through interactive voice response telephone messages to promote weight loss in a pre-diabetic population. Patient Educ Counsel 2008;72(1):34–41.
[41] Fischer HH, Fischer IP, Pereira RI, et al. Text message support for weight loss in patients with prediabetes: a randomized clinical trial. Diabetes Care 2016;39(8): 1364.
[42] Griauzde D, Kullgren JT, Liestenfeltz B, et al. A mobile phone-based program to promote healthy behaviors among adults with prediabetes who declined participation in free diabetes prevention programs: mixed-methods pilot randomized controlled trial. JMIR Mhealth Uhealth 2019;7(1):e11267.
[43] Irvine L, Barton GR, Gasper AV, et al. Cost-effectiveness of a lifestyle intervention in preventing Type 2 diabetes. Int J Technol Assess Health Care 2011;27(4): 275–82.
[44] Limaye T, Kumaran K, Joglekar C, et al. Efficacy of a virtual assistance-based lifestyle intervention in reducing risk factors for Type 2 diabetes in young employees in the information technology industry in India: LIMIT, a randomized controlled trial. Diabet Med 2017;34(4):563–8.
[45] Morey MC, Pieper CF, Edelman DE, et al. Enhanced fitness: a randomized controlled trial of the effects of home-based physical activity counseling on glycemic control in older adults with prediabetes mellitus. J Am Geriatr Soc 2012; 60(9):1655–62.
[46] Nanditha A, Thomson H, Susairaj P, et al. A pragmatic and scalable strategy using mobile technology to promote sustained lifestyle changes to prevent type 2 diabetes in India and the UK: a randomised controlled trial. Diabetologia 2020;63 (3):486–96.
[47] Ramachandran A, Snehalatha C, Ram J, et al. Effectiveness of mobile phone messaging in prevention of type 2 diabetes by lifestyle modification in men in India: a prospective, parallel-group, randomised controlled trial. Lancet Diabetes Endocrinol 2013;1(3):191–8.
[48] Ram J, Selvam S, Snehalatha C, et al. Improvement in diet habits, independent of physical activity helps to reduce incident diabetes among prediabetic Asian Indian men. Diabetes Res Clin Pract 2014;106(3):491–5.
[49] Sakane N, Kotani K, Takahashi K, et al. Effects of telephone-delivered lifestyle support on the development of diabetes in participants at high risk of type 2 diabetes: J-DOIT1, a pragmatic cluster randomised trial. BMJ Open 2015;5(8): e007316.
[50] Sakane N, Kotani K, Suganuma A, et al. Prevention of metabolic syndrome by telephone-delivered lifestyle intervention in a real-world setting: sub-analysis of a cluster-randomized trial. Metab Syndr Relat Disord 2019;17(7):355–61.
[51] Staite E, Bayley A, Al-Ozairi E, et al. A wearable technology delivering a web-based diabetes prevention program to people at high risk of type 2 diabetes: randomized controlled trial. JMIR Mhealth Uhealth 2020;8(7):e15448.
[52] Wong CKH, Fung CSC, Siu SC, et al. A short message service (SMS) intervention to prevent diabetes in Chinese professional drivers with pre-diabetes: a pilot single-blinded randomized controlled trial. Diabetes Res Clin Pract 2013;102(3):158–66.
[53] Wong CKH, Jiao F-F, Siu S-C, et al. Cost-effectiveness of a short message service intervention to prevent type 2 diabetes from impaired glucose tolerance. J Diabetes Res 2016;2016:1219581.
[54] Wong CKH, Siu S-C, Wong K-W, et al. Five-year effectiveness of short messaging service (SMS) for pre-diabetes. BMC Res Notes 2018;11(1). 709-709.
[55] Xiao H, Adams SR, Goler N, et al. Wellness coaching for people with prediabetes: a randomized encouragement trial to evaluate outreach methods at kaiser permanente, northern California, 2013. Prev Chronic Dis 2015;12. E207-E207.
[56] Ackermann RT, Sandy LG, Beauregard T, et al. A randomized comparative effectiveness trial of using cable television to deliver diabetes prevention programming. Obesity 2014;22(7):1601–7.
[57] Fottrell E, Ahmed N, Morrison J, et al. Community groups or mobile phone messaging to prevent and control type 2 diabetes and intermediate hyperglycaemia

in Bangladesh (DMagic): a cluster-randomised controlled trial. Lancet Diabetes Endocrinol 2019;7(3):200–12.
[58] Fukuoka Y, Gay CL, Joiner KL, et al. A novel diabetes prevention intervention using a mobile app: a randomized controlled trial with overweight adults at risk. Am J Prev Med 2015;49(2):223–37.
[59] McLeod M, Stanley J, Signal V, et al. Impact of a comprehensive digital health programme on HbA1c and weight after 12 months for people with diabetes and prediabetes: a randomised controlled trial. Diabetologia 2020;63(12):2559–70.
[60] Toro-Ramos T, Michaelides A, Anton M, et al. Mobile delivery of the diabetes prevention program in people with prediabetes: randomized controlled trial. JMIR Mhealth Uhealth 2020;8(7):e17842.
[61] Al-Hamdan R, Avery A, Al-Disi D, et al. Efficacy of lifestyle intervention program for Arab women with prediabetes using social media as an alternative platform of delivery. J Diabetes Investig 2021;12(10):1872–80.
[62] Bootwong P, Intarut N. The effects of text messages for promoting physical activities in prediabetes: a randomized controlled trial. Telemedicine and e-Health 2021;28(6):896–903.
[63] Heisler M, Dyer WT, Finertie H, et al. Using peer support to prevent diabetes: results of a pragmatic RCT. Am J Prev Med 2023;65(2):239–50.
[64] Lakka TA, Aittola K, Järvelä-Reijonen E, et al. Real-world effectiveness of digital and group-based lifestyle interventions as compared with usual care to reduce type 2 diabetes risk - a stop diabetes pragmatic randomised trial. Lancet Reg Health Eur 2023;24:100527.
[65] Lim SL, Ong KW, Johal J, et al. A smartphone app-based lifestyle change program for prediabetes (D'LITE study) in a multiethnic asian population: a randomized controlled trial. Front Nutr 2022;8:780567.
[66] Han CY, Lim SL, Ong KW, et al. Behavioral lifestyle intervention program using mobile application improves diet quality in adults with prediabetes (D'LITE study): a randomized controlled trial. J Acad Nutr Diet 2024;124(3):358–71.
[67] Muralidharan S, Ranjani H, Mohan Anjana R, et al. Engagement and weight loss: results from the mobile health and diabetes trial. Diabetes Technol Therapeut 2019;21(9):507–13.
[68] Diabetes Prevention Program Research Group. The Diabetes Prevention Program (DPP): description of lifestyle intervention. Diabetes Care 2002;25(12):2165–71.
[69] Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002;346(6):393–403.
[70] Franz MJ. Weight management: obesity to diabetes. Diabetes Spectr 2017;30(3): 149–53.
[71] Bergman M, Buysschaert M, Schwarz PE, et al. Diabetes prevention: global health policy and perspectives from the ground. Diabetes Manag (Lond). 2012;2(4): 309–21.
[72] Glechner A, Keuchel L, Affengruber L, et al. Effects of lifestyle changes on adults with prediabetes: a systematic review and meta-analysis. Prim Care Diabetes 2018; 12(5):393–408.
[73] Murray E, Hekler EB, Andersson G, et al. Evaluating digital health interventions: key questions and approaches. Am J Prev Med 2016;51(5):843–51.
[74] Alliance for Affordable Internet. From luxury to lifeline: reducing the cost of mobile devices to reach universal internet access. 2020.