Clinical and patient-centered implementation outcomes of mHealth interventions for type 2 diabetes in low-and-middle income countries: a systematic review

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Abstract

Background: The prevalence of Type 2 Diabetes is rising in Low- and Middle-Income Countries (LMICs), affecting all age categories and resulting in huge socioeconomic implications. Mobile health (mHealth) is a potential high-impact approach to improve clinical and patient-centered outcomes despite the barriers of cost, language, literacy, and internet connectivity. Therefore, it is valuable to examine the clinical and implementation outcomes of mHealth interventions for Type 2 Diabetes in LMICs.

Methods: The Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) guidelines were applied in framing and reporting the review criteria. A systematic search of Cochrane Library, Web of Science, PubMed, Scopus, and Ovid databases was performed through a combination of search terms. Randomized Controlled Trials (RCTs) and cohort studies published in English between January 2010 and August 2021 were included. Risk of bias for missing results in the included studies was assessed using the Cochrane risk-of-bias tool for randomized trials (RoB 2). Quantitative and qualitative methods were used to synthesize the results.

Results: The search identified a total of 1161 articles. Thirty studies from 14 LMICs met the eligibility criteria. On clinical outcomes, 12 and 9 studies reported on glycated hemoglobin (HbA1c) and fasting blood glucose (FBG) respectively. Text messages was the most commonly applied mHealth approach, used in 19 out of the 30 studies. Ten out of the 12 studies (83.3%) that reported on HbA1c had a percentage difference of <0.3% between the mHealth intervention and the comparison group. Additionally, studies with longer intervention periods had higher effect size and percentage difference on HbA1c (1.52 to 2.92%). Patient-centred implementation outcomes were reported variably, where feasibility was reported in all studies. Acceptability was reported in nine studies, appropriateness in six studies and cost in four studies. mHealth evidence reporting and assessment (mERA) guidelines were not applied in all the studies in this review.

Conclusion: mHealth interventions in LMICs are associated with clinically significant effectiveness on HbA1 but have low effectiveness on FBG. The application of mERA guidelines may standardize reporting of patient-centered implementation outcomes in LMICs.

Trial registration: PROSPERO: Registration ID 154209.
Introduction
Type 2 Diabetes is now a leading public health problem in Low-and Middle Income Countries (LMICs) [1] affecting all age categories and resulting in huge economic implications to healthcare [2, 3]. LMICs are home to 80% of all people with type 2 diabetes (336 million) [4] and more than 80% of all undiagnosed people with diabetes [2]. It is projected that between 2019 and 2030, the prevalence of type 2 diabetes is likely to increase from 13.5% to 15.0% in LMICs compared to 10.4% to 11.4% in high-income countries [2]. Further, out of the total number of deaths related to diabetes globally, 41.8% and 58.2% occur in Low-and Middle-income Countries, respectively [2]. The rising prevalence of type 2 diabetes in LMICs is attributed to the nutrition transition, and the increasing prevalence of overweight and obesity. The other factors include urbanization, cultural and social changes, sedentary lifestyles, changes in diagnostic criteria and screening practices [5–7].

Optimal diabetes management requires a systematic approach, and the involvement of a coordinated, multidisciplinary team that is committed to patient-centered outcomes [8]. It is recommended that clinicians apply a patient-centered approach and minimum clinically important difference (MCID) treatment models by considering the statistical significance and clinical significance of research findings [9]. Essential guidelines for the patient-centered approach include individualized therapy and shared decision-making [10]. Additionally, effective patient-centered diabetes self-management requires the support and promotion of essential self-care behaviors [11]. These behaviors include healthy eating, physical activity, medication usage, monitoring and usage of patient-generated data, prevention, detection and treatment of acute and chronic complications, healthy coping with psychosocial issues and problem solving [12]. These behaviors have been described as Diabetes Self-Management Education and Support (DSMES) domains. Self-management education is linked to clinically important benefits on glycated hemoglobin (HbA1c), and cost of treatment [13–18]. This notwithstanding, self-care in most LMICs is not optimally attained due to disadvantaged access to healthcare and low-quality healthcare, poverty, low literacy levels and incorrect perceptions about diabetes [19–21].

The remarkable increase in ownership and use of mobile phones in LMICs provides a potential opportunity for the application of mobile health (mHealth) in self-care and behavior change interventions for type 2 diabetes [22–24]. mHealth is the medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices [25]. Evidence shows that mHealth has the potential to facilitate accessibility and coverage of healthcare services as well as positively influencing clinical outcomes, compliance, self-care practices and quality of life for people with type 2 diabetes [26–29]. Whereas there is close similarity between mHealth and eHealth, the later refers to an emerging field that links medical informatics, public health and business, that delivers or enhances health services and information via web-based technologies [30]. However, eHealth heavily relies on internet technology, which limits its applicability in LMICs, due to unreliable access to internet [31].

A recent metanalysis on mHealth interventions for diabetes in LMICs revealed promising but limited evidence on the effectiveness of mHealth interventions on glycemic control [32]. Further, a pooled effect on HbA1c from three studies on mobile phone–based interventions showed a larger effect of 25.46 mmol/mol or 20.50%; (95% CI 20.7 to 20.3%; I2 = 0%) [33]. mHealth interventions have also been found to be cost-effective [34] despite being criticized for having meager user satisfaction ratings coupled with usability challenges [35]. In LMICs, a few studies on mHealth have shown changes in clinical outcomes, adherence and improved communication with providers, decreased travel time, ease to receive expert advice and cost-effective education [36].

Further, evidence from LMICs reveal unique patient circumstances that hinder optimal utilization of mHealth approaches. Inadequate resources, low digital literacy and low health literacy and limited inclusion of motivation techniques hinder optimal utilization of mHealth in LMICs [37]. As such, distinguishing treatment effectiveness or clinical outcomes from implementation effectiveness is important for transferring interventions from experimental settings to the community [38, 39]. This distinction, to the best of our knowledge, has not been examined on mHealth interventions for type 2 diabetes in LMICs.

The objective of this systematic review therefore was to examine the clinical outcomes and patient-centered implementation outcomes of mHealth interventions with a focus on type 2 diabetes in LMICs.

Methods
Data sources and registration
This review applied the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA)
guidelines [40] with the PICOS framing. The review has been registered and amended in PROSPERO [https://www.crd.york.ac.uk/prospero/#recordDetails] (Registration ID 154209) and funded by VLIR-UOS (Grant-number: KE2017UC037A101).

Search strategy
The search strategy was applied on Cochrane and Web of Science Cochrane Library, Web of Science, PubMed, Scopus, and Ovid databases. (Supplementary File 1). These databases were systematically searched with Boolean combinations of key words and MeSH headings. An electronic search was conducted using the following terms and Boolean Operators: ((mobile health OR mHealth) AND/OR (type 2 diabetes) AND/OR (DSMES) AND/OR (acceptability) AND/OR (appropriateness) AND/OR (feasibility) AND/OR (cost) AND/OR (sustainability)). Acceptability, appropriateness, feasibility, cost and sustainability were based on the definitions in the conceptual framework for implementation outcomes by Proctor et al. [38]. We searched for articles published in English between January 2010 and August 2021. Additional records were searched through citations from relevant reviews given that online data bases can be incomplete [41].

Study selection
This review included randomized controlled trials (RCTs), cluster randomized controlled trials, feasibility studies and prospective observational cohort studies from LMICs. The search also included cohort and follow-up studies of intervention studies that have been published in peer-reviewed journals. Our review was limited to studies that are designed for adults diagnosed with type 2 diabetes. We included studies in which the mHealth intervention was designed to be an enabler for delivery of DSMES for patients with type 2 diabetes [1]. mHealth or mobile health are medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices as defined by WHO [25]. DSMES domains include diabetes pathophysiology and treatment options; healthy eating; physical activity; medication usage; monitoring and usage of patient generated health data; prevention, detection, and treatment of acute and chronic complications; healthy coping with psychosocial issues; and problem solving [42]. The selection of studies was conducted by MM and independently reviewed by FK, CM and RV. We excluded studies on children and adolescents, pregnant women, or any other forms of diabetes besides type 2 diabetes such as pre-diabetes, type 1 diabetes or gestational diabetes [43]. We also excluded studies where the mHealth intervention was designed for to support healthcare workers and those studies that did not target the patient.

Data collection process
Data from all eligible articles was summarized by the first author (MM) and reviewed by the second and third authors (FK & CM) using structured evidence tables (Table 1 & 2). A standardized criterion for data collection was designed by the authors to extract and tabulate relevant study characteristics. These characteristics include study location, study type, duration of study, clinical outcomes (HbA1c and FBG), mHealth intervention and function, DSMES domains and patient-centered implementation outcomes.

Quality of studies and risk of bias assessment
To assess quality of the articles, we applied the 2010 CONSORT (Consolidated Standards of Reporting Trials) guidelines [75] and the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines [76]. This approach has been used elsewhere to assess the quality of studies [77–79]. An analysis of the quality of the studies included in this review is presented as heat maps (Supplementary File 2). A percentage quality score of >66.6% is rated as high, 50-66.6% as fair and <50% as low. Assessment of quality was conducted by two independent researchers, MM and ES. Additionally, the risk of bias in the included studies was assessed using the Cochrane risk of bias tool for randomized trials (RoB 2) (Supplementary File 3).

Summary measures
The primary outcome measures in this study are clinical outcomes and patient-centered implementation outcomes for type 2 diabetes mHealth interventions. Specifically, clinical outcomes were synthesized using quantitative methods based on effect sizes of HbA1c and FBG. HbA1c and FBG measure the effectiveness of interventions for the management of type 2 diabetes [80]. Additionally, the percentage difference between the mHealth intervention and the comparison group for HbA1c was analyzed. The patient centered implementation outcomes included acceptability, feasibility, appropriateness, cost and sustainability [38, 81–84]. Acceptability is the perception amongst implementation stakeholders that a particular treatment, service is agreeable, palatable, or satisfactory [33]. Appropriateness is the perceived fit, relevance or compatibility of the innovation for a given practice setting, provider or consumer; and/or perceived fit of the innovation to address a particular issue [33]. Cost is defined as the incremental, implementation or
| Study and location | Study Design | Sample Size | Participant Age (Years) | Duration of Intervention | mHealth intervention delivery |
|--------------------|--------------|-------------|-------------------------|--------------------------|-------------------------------|
| Anzaldo et al. [44] Mexico | RCT | n=301; I1: (Project Dulce)102; I2: (Project Dulce with Technology enhancement) 99; C: 100 | 18-75 | 10 months | Arm 1: PD TE: Interactive surveys, text messages, short educational videos; Arm 2: PD: combination of care management by a multidisciplinary team led by trained clinicians and nurses, as well as a peer-led group education Bidirectional |
| Chai et al. [45] China | Cohort | n=209 | Mean age: 51.97 ± 12.76 | 4 Months | Upload insulin dosages three or more times for the FPG and postprandial plasma glucose (PPG) on a panel computer |
| Chao et al. [46] China | RCT | n=121; I: 62; C: 59 | C: Not provided; I: 63.71 (37-88) | 18 months | mobile app; Cloud-based IPMF Bidirectional |
| Dong et al. [47] China | RCT | n=120 | I: 60; C: 60 | 12 months | Web-based app: WeChat platform Bidirectional |
| Doocy et al. [48] Lebanon | Longitudinal Cohort | 10 HC; 1020 | < 40 a | 20 months | mHealth app (PCHR), |
| Fottrell et al. [49] India | CRCT | n=13,728; I1: 4,093; I2: 4,079; C: 5,008; | Mean Age not provided; Adults ≥30 | 18 months, | 1. Voice messages 2-weekly (14 months); 2. Monthly PLA group meetings (with a 4-phase PLA cycle) |
| Gunawardena et al. [50] Sri Lanka | RCT | n=67; I: 35; C: 32 | I: 53 (SD 11); C: 52 (SD 12) | 6 months | Android based Smart Glucose Manager (SGM) every 3 months Text Messages: 4weekly messages Unidirectional |
| Goodarzi et al. [51] Iran | RCT | n=100; I: 50; C: 50 | 150.98 (SD = 1032); I: 56.71 (SD = 977) | 3 months | Text Messages: 1 message per week 5 Bidirectional |
| Haddad et al. [52] Iraq | Feasibility RCT | n=50 | Mean: 51.4 (SD 10.3) | 6 months | Text Messages 6 SMSs per week for 6 months; Weekly unidirectional messages Bidirectional |
| Huo et al. [53] China | RCT | n=502; I: 251; C: 251 | Mean: 59.5 (SD 9.4); I: 59.5 (SD 9.1); C: 59.5 (SD 9.3) | 6 months | Text messages and Voice calls to the study team for any queries in response to the text message (with a 2-day response) Bidirectional |
| Islam et al. [54] Bangladesh | RCT | n=236; I:108; C:108 | mean age: SD: 48.1 ± 6.97 | 6 Months | |
| Study and location | Study Design | Sample Size | Participant Age (Years) | Duration of Intervention | mHealth intervention delivery |
|--------------------|--------------|-------------|--------------------------|--------------------------|-------------------------------|
| Kumar et al. [55]  | RCT          | n=955       | I: 57.5 (SD 10.8)        | 12 months                | Text Messages                  |
| India              |              | I: 479, C: 476 | C: 57.0 (SD 10.7)        |                          | Patient specific frequency      |
|                    |              |             |                          |                          | (average of 2 times per month  |
|                    |              |             |                          |                          | for 12 months)                 |
|                    |              |             |                          |                          | Unidirectional                 |
| Li et al. [56]     | RCT          | n=101       | 48.2 (SD 10.4)           | 3 months                 | R Plus Health app              |
| China              |              | I: 55, C: 46 |                          |                          | (Recovery Plus Inc), which      |
|                    |              |             |                          |                          | connected wirelessly           |
|                    |              |             |                          |                          | to a chest-worn heart rate     |
|                    |              |             |                          |                          | band (Recovery Plus Inc)       |
| Liao et al. [57]   | CRCT         | n=149       | Mean age: 62             | 3 months                 | Wrist-worn activity trackers   |
| China              |              | I: 69, C: 80 |                          |                          | (Lifesense MAMBO2 wristbands)   |
|                    |              |             |                          |                          | Activity uploaded to the cloud  |
|                    |              |             |                          |                          | via a paired smartphone device |
|                    |              |             |                          |                          | Physical activity reports on   |
|                    |              |             |                          |                          | the paired smartphone via      |
|                    |              |             |                          |                          | WeChat without support and     |
|                    |              |             |                          |                          | peers                         |
| Limaye et al. [58] | RCT          | n=265       | Mean: 36.2 (SD 93)       | 12 months                | Text messages: 3 per wk        |
| India              |              | I: 132, C: 133 | I: 36.8 (7.2)          |                          | Emails: 2 e-mails/wk between   |
|                    |              |             |                          |                          | 1000–1300 h;                   |
|                    |              |             |                          |                          | Website and Facebook           |
|                    |              |             |                          |                          | Bidirectional                  |
|                    |              |             |                          |                          | 10% of messages required reply |
| Olmen et al. [59]  | RCT          | N=1471      | Overall: NP              | 24 months                | Text Messages                   |
| Congo Cambodia     |              | Congo: 506, | I: 58 (SD 10)           |                          | Congo: 5 times/wk; Cambodia:   |
| Philippines        |              | Cambodia: 484; | C: 60 (SD 10)        |                          | 6 times/wk; Philippines: 2 times/|
|                    |              | Philippines: 481; |                      |                          | week                           |
|                    |              |             |                          |                          | Voice messages                 |
|                    |              |             |                          |                          | Cambodia ¼ of all messages to   |
|                    |              |             |                          |                          | specific groups,               |
|                    |              |             |                          |                          | Unidirectional                 |
| Owolabi et al. [60]| RCT          | n=216       | Overall: 60.64 (SD 11.58) | 6 Months                 | Standard of care plus          |
| South Africa       |              | I: 108, C: 108 |                      |                          | Tailored Short message services|
|                    |              |             |                          |                          | (SMS)                         |
| Owolabi et al. [61]| RCT          | n=216       | Overall: 60.64 (SD 11.58) | 6 Months                 | Text Messages                   |
| South Africa       |              | I: 108, C: 108 |                      |                          | Daily SMS: 2 times a week      |
| Patnaik et al. [62]| RCT          | n=66        | 42.29 (SD 9.5)          | 24 Months                | Mobile-based android application|
| India              |              | I: 33, C: 33 |                          |                          | Bi-directional                 |
| Study and location          | Study Design | Sample Size | Participant Age (Years) | Duration of Intervention | mHealth intervention delivery                                                                 |
|-----------------------------|--------------|-------------|-------------------------|--------------------------|-----------------------------------------------------------------------------------------------|
| Peimani et al. [63] Iran    | RCT          | n=150       | I1: 49.78 (SD 9.76)      | 3 months                 | Text MessagesVoice CallsArm 1: individually tailored SMS each person received 75% of their     |
|                             |              |             | I2: 52.36 (SD 10.49)     |                          | messages tailored to 2 reported barriers to adherenceArm 2: non-tailored SMS: random         |
|                             |              |             | I3: 54.56 (SD 9.88)      |                          | messages sent irrespective of barriers with Voice CallsWeeklyArm 3: text messages and        |
|                             |              |             |                         |                          | interactive voice calls (Voice Calls) with messages tailored to barriers to adherence.        |
|                             |              |             |                         |                          |                                                                                               |
| Pichayapinyo et al. [64]    | Cohort       | n=35        | 54.9 (SD 6.3)            | 4 Months                 | Interactive Voice Response (IVR) & email content was translated into ThaiIVR calls lasting 5–10 |
| Thailand                    |              |             |                         |                          | minutes each for 12 weeks                                                                      |
| Pfammatter et al. [65] India| Parallel Cohort | n= 1925 | Overall: 32.2 (SD 10.6) | 6 months (Dec 2012-June 2013) | Text Messages (Multilanguage text) Daily text messages for the first 6 days followed by 2 SMSs  |
|                             |              |             | I: 32.83 (SD 9.39) C: 31.66 (SD 11.64) |                          | per week Unidirectional                                                                    |
|                             |              |             | I: 31.66 (SD 11.64)      |                          |                                                                                               |
| Rasoul et al. [66] Iran     | RCT          | n=98        | 32.1 (SD 4.9)            | 5 months                 | Weblogs: Text, video, recorded voice, and nutrition pyramid for diabetic patients3 days/week:  |
|                             |              |             |                         |                          | 1:30 hr/sessionTotal: 60 sessions                                                              |
|                             |              |             |                         |                          |                                                                                               |
| Rotheram-Borus et al. [67]  | Cohort       | n=22 (Women)| 53 (SD 12.8)            | 3 months followed by a post-trial FU at 6 months                                               |
| South Africa                |              |             |                         |                          |                                                                                               |
| Shahid et al. [68] Pakistan | RCT          | n=440       | I: 48.93 SD(8.83), C 49.21 (SD 7.92) | 6 months                 | Voice calls Calls every 15 days for a period of 4 months: Total of 8 calls                   |
|                             |              |             | I: 220 C: 220           |                          |                                                                                               |
| Steinman et al. [69] Cambodia| CRCT        | n=3948      | NR                      | 12 months                 | Tablet and mobile voice messages delivered via patient’s mobile phones                       |
|                             |              |             | C: 1,737, I: 1,099      |                          |                                                                                               |
| Sun et al. [70] China       | RCT          | n=91        | Overall: NP             | 6 months                 | Mobile ApplicationBidirectional                                                               |
|                             |              |             | I: 68.04 (66-72)        |                          |                                                                                               |
|                             |              |             | C: 67.9 (66-71)         |                          |                                                                                               |
| Study and location   | Study Design | Sample Size       | Participant Age (Years)                          | Duration of Intervention | mHealth intervention delivery |
|---------------------|--------------|-------------------|-------------------------------------------------|--------------------------|------------------------------|
| Wang et al. [71]    | RCT          | n=120             | Mean age: 45.4                                   | 6 months                 | Mobile application           |
| China               |              | I: 60, C:60       |                                                 |                          |                              |
| Yasmin et al. [72]  | RCT          | n=320             | I: 53 [30–85] C: 51 [30–75]                      | 12 months                | Personalized Voice calls     |
| Bangladesh          |              | I: 160            |                                                 |                          | every 10 days, except Fridays|
|                     |              | C: 160            |                                                 |                          | and other national holidays  |
| Zhou et al. [73]    | RCT          | n=100             | Overall: NP                                      | 3 months                 | Mobile Application           |
| China               |              | I: 50             |                                                 |                          | Welttang mobile App          |
|                     |              | C: 50             |                                                 |                          | App for both pts and clinician:|
|                     |              |                   |                                                 |                          | 1. Transfers data to servers.|
|                     |              |                   |                                                 |                          | Every per week/ Every 2 wks.|
|                     |              |                   |                                                 |                          | Feedback: 3-10mins           |

App Application; Personally controlled health record; PD Project Dulce—only; PD-TE Project Dulce technology enhanced with mobile tools; PPG postprandial plasma glucose; PT Patient; QA Question and answer; SBP systolic Blood Glucose; T2DM type 2 Diabetes Mellitus; Mean age not provided; Interquartile rage
overall costs of delivery based on the settings [33]. Feasibility is the extent to which a new treatment, or an innovation, can be successfully applied or implemented in a specific setting [34]. Sustainability is the extent to which an implemented treatment is maintained within a service setting’s usual or stable operations, as defined by various authors [35–37].

**Synthesis of results**

To conduct a quantitative synthesis for clinical outcomes, standardized effect sizes were calculated using two-stage process [85]. In the first stage the effect size of HbA1c and FBG was calculated separately for each study from means and standard deviations. In the second stage, the combined effect size as a weighted average of the intervention effects was derived from the individual studies. The effect sizes were calculated using the formula $d = (\text{post} - \text{pre}) / \text{std ev}$ to account for between group and within group comparisons. Cohen’s $d$ was calculated to derive standardized effect sizes and then converted into Hedges’ $g$ to correct for their upwards bias [86]. The magnitude of Hedges’ $g$ was interpreted using Cohen’s convention where an effect size of $< 0.20$ is considered to be small, $0.50$ to $0.80$ as medium, while scores $> 0.80$ as large [87].

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**Table 2** Clinical and patient-centred Implementation outcomes

| Study | Clinical Outcomes | Patient-centred Implementation outcomes |
|-------|-------------------|----------------------------------------|
| Anzaldo et al. [44] | HbA1c, TC, LDL-c, HDL-c, BMI, SBP, DBP | Feasibility, Appropriateness, Acceptability |
| Chai et al. [45] | FPG $\leq$ 7 mmol/l, PPG $\leq$ 10 mmol/l, HbA1c level $\leq$ 7% | Feasibility, Appropriateness |
| Chao et al. [46] | Hb, HbA1c, weight, BMI | Feasibility, Appropriateness |
| Dong et al. [47] | FPG, 2hPG, HbA1c | Feasibility |
| Doocy et al. [48] | HbA1c, BP, FBG | Feasibility |
| Fottrell et al. [49] | PA, BP, HR, Waist Circumference, weight, Height, QOL, Urine Cotinine | Feasibility, Acceptability, Cost |
| Goodarzi et al. [51] | BMI, L-FBG, HbA1c, TC, TG, HDL-C, LDL-C, BUN, Cra, SE, SBP, DBP | Feasibility, Appropriateness |
| Gunawardena et al. [50] | HbA1c | Feasibility |
| Haddad et al. [52] | Knowledge, HbA1c, cost | Feasibility, Acceptability, Cost, Appropriateness |
| Huo et al. [53] | Primary: HbA1c, Secondary: FBG, LDL, LDL-C, SBP, BMI, PA | Feasibility, Appropriateness, Cost |
| Islam et al. [74] | HbA1c | Feasibility |
| Kumar et al. [55] | FBG, TC, BMI, BP | Feasibility |
| Li et al. [56] | BMI, hemoglobin HbA1c, HOMA-IR, Resting heart rate (bpm) | Feasibility |
| Liao et al. [57] | Heart rate | Acceptability, Feasibility, Appropriateness |
| Limaye et al. [58] | BMI, weight, waist circumference, BP, FBG, LDL-C, HDL-C | Acceptability, Feasibility, Cost, Sustainability |
| Owolabi et al. [60] | Diet adherence, PA adherence | Acceptability, Feasibility, Appropriateness |
| Owolabi et al. [61] | RBS, BMI, SBP, DBP | Acceptability, Feasibility |
| Patnaik et al. [62] | HbA1c | Feasibility, Appropriateness |
| Peiman et al. [63] | HbA1c, FBG, LDL-C, HDL-C, SCI, BMI, DMSES | Feasibility |
| Pichayapinyo et al. [64] | HbA1c, FBG | Feasibility, Acceptability |
| Pfammatter et al. [65] | Fruit, vegetable and fat consumption; Exercises | Feasibility, Acceptability |
| Rasoul et al. [66] | FBG, BMI, SBP, DBP | Feasibility |
| Rotheram-Borus et al. [67] | HbA1c, BMI, BP | Feasibility |
| Shahid et al. [68] | HbA1c, LDL | Feasibility |
| Steinman et al. [69] | FBG, SBP, DBP | Feasibility, Sustainability |
| Sun et al. [70] | HbA1c, PBG, FBG, BMI, TG, HDL-C, LDL-C Cr, AST | Feasibility |
| Wang et al. [71] | HbA1c, FPG | Appropriateness, Feasibility |
| Yasmin et al. [72] | FBS $< 7.0$ mmol/L, and the PPG 2 h after breakfast $< 11.1$ mmol/L | Feasibility |
| Zhou et al. [73] | HbA1c, BP, LDL-C, weight, BG, Satisfaction, T2DM knowledge | Feasibility |

AST aspartate transaminase; BG Blood Glucose; BMI Body Mass Index; BP Blood pressure; Cr Creatinine; DSME Diabetes Self-Management and Education; FBG Fasting Blood glucose; FBS Fasting Blood Glucose; FU follow-up; HbA1c Glycated Haemoglobin; HDL-c High Density Lipoprotein Cholesterol; I1 First Intervention Arm; I2 Second Intervention Arm; IPMF Interactive personalized management framework; IVR Interactive Voice Response; LDL-c Low Density Lipoprotein Cholesterol; Med medication; Mos Months; NO Number of; NP Not Provided; OP outpatient; PA Physical Activity; PBG Post prandial Blood Glucose; PCHR Personally controlled health record; TC Total cholesterol; TG Triglycerides
The five patient-centered implementation outcomes were analyzed in an excel spreadsheet and presented descriptively.

**Results**
The search identified a total of 1,161 articles. After removal of duplicates, 1,116 titles of articles were screened and a total of 30 studies that met the eligibility criteria were included in this review (Fig. 1). The 30 eligible studies include 21 randomized controlled trials [44, 46, 47, 50, 51, 53–56, 58–62, 66, 68, 70–74], two feasibility randomized controlled trials [52, 63], three cluster randomized control trials [49, 57, 69] and five cohort studies [45, 48, 64, 65, 67]. The studies were conducted in 14 LMICs including nine in China [45–47, 53, 56, 57, 70, 73, 88], five in India [49, 58, 62, 65, 89], three in South Africa [60, 61, 67], three in Iran [51, 63, 66], two in Bangladesh [49, 54] and one each in Iraq [52], Lebanon [48], Pakistan [68], Mexico [44], Cambodia [69] and Thailand [64]. One other study was multicentre, conducted in Congo, Cambodia and Philippines [59].

**Study quality**
The overall mean rating based on these checklists for the randomized controlled trials and cohort studies was 81.8% and 87.7% respectively and categorized as high quality (Supplementary Files 2).

**Study and sample characteristics**
The 30 studies included a total of 27,142 participants (Mean =904.7 SD=2548.6) published between 2010-2021, with 66.7% published between 2017 to 2021. The mean duration of the studies was 8.9 months (SD=6.4 min-max: 3-24 months).
Table 3 Categories and functions of mHealth

| Category of mHealth                                   | Function                      | Studies                                                        |
|-------------------------------------------------------|-------------------------------|----------------------------------------------------------------|
| Mobile technology and devices, including mobile       | Knowledge and tips            | Dong et al. [47], Goodarzi et al. [51], Huo et al. [53]         |
| phone text messages (MPTMs)                           |                               | Islam et al. [90]                                              |
|                                                        | Suggestions                   | Haddad et al. [52], Limaye et al. [58], Owolabi et al. [61],   |
|                                                        |                               | Owolabi et al. [60], Peimani et al. [63], Pfammatter et al.   |
|                                                        |                               | [65], Rotheram-Borus et al. [67], Islam et al. [90], Kumar et  |
|                                                        |                               | al. [55]                                                      |
|                                                        | Reminder                      | Huo et al. [53]                                                |
|                                                        | Medical consultations         | None                                                           |
|                                                        | Feedback                      | Huo et al. [53], Haddad et al. [52], Limaye et al. [58],       |
|                                                        |                               | Peimani et al. [63], Rotheram-Borus et al. [67], Islam et al.  |
|                                                        |                               | [90], Liao et al. [57]                                         |
|                                                        |                               |                                                               |
| Telemedicine                                          | Knowledge and tips            | Rasoul et al. [66], Chai et al. [45]                            |
|                                                        | Suggestions                   | Limaye et al. [58], Rasoul et al. [66]                          |
|                                                        | Reminder                      | None                                                           |
|                                                        | Medical consultations         | None                                                           |
|                                                        | Feedback                      | Liao et al. [57]                                               |
|                                                        |                               |                                                               |
| Mobile Phone Calls (MPCs)                             | Knowledge and tips            | Fottrell et al. [49]                                           |
|                                                        | Suggestions                   | Yasmin et al. [72], Shahid et al. [68], Pichayapinyo et al.   |
|                                                        |                               | [64], Steinman et al. [69]                                     |
|                                                        | Reminder                      | Yasmin et al. [72], Shahid et al. [68]                         |
|                                                        | Medical consultations         | None                                                           |
|                                                        | Feedback                      | Yasmin et al. [72], Anzaldo-Campos et al. [64]                 |
| mHealth Apps                                          | Knowledge and tips            | Wang et al. [71], Li et al. [56]                               |
|                                                        | Suggestions                   | Chai et al. [45], Sun et al. [70], Wang et al. [71], Chao et  |
|                                                        |                               | [46]                                                           |
|                                                        | Medical consultations         | Zhou et al. [73], Anzaldo-Campos et al. [44], Patnaik et al.  |
|                                                        |                               | [62]                                                           |
|                                                        | Reminder                      | Zhou et al. [73], Gunawardena et al. [50], Liao et al. [57],   |
|                                                        |                               | Li et al. [56], Wang et al. [71]                               |
|                                                        | Data monitoring/ collection/  | Doocy et al. [48], Patnaik et al. [62],                       |
|                                                        | store/ transmit               | Zhou et al. [73], Anzaldo-Campos et al. [44]                   |
|                                                        | Feedback                      | Zhou et al. [73], Gunawardena et al. [50], Liao et al. [57],   |
|                                                        |                               | Li et al. [56]                                                 |
| Wearable or Portable Monitoring Devices (WPMDs)        | Data monitoring/ collection/  | Sun et al. [70], Gunawardena et al. [50], Liao et al. [57],   |
|                                                        | store/ transmit               | Li et al. [56]                                                 |

mHealth interventions

Table 3 below categorizes mHealth interventions based on the WHO categorization [25]. In summary text mobile phone text messages (MPTMs) was the most applied mHealth approach, applied in 19 studies. Mobile apps were applied in 10 studies while four studies [50, 56, 57, 70] applied wearable or portable monitoring devices to monitor blood glucose, physical activity or heartbeat rate.

Clinical outcomes of mHealth intervention

To examine clinical outcomes in this review, we examined changes in HbA1c and FBG. HbA1c (mean SD) was reported in 12 studies [44, 46, 47, 51, 53, 56, 63, 64, 68, 70, 71, 73] (Table 4). As summarized in Table 4, one study [47] had a large effect size (Cohen’s d = 1.15) while three studies [44, 46, 73] reported a medium effect size (Cohen’s d = 0.57). Five of the 12 studies that reported HbA1c had a small effect size (Table 4). Ten out of the twelve studies (83.3%) that reported on HbA1c had a percentage difference of <0.3% between the mHealth intervention and the comparison group. Pichayapinto et al [64] only reported the effect size (Cohen’s d = -0.5) and hence the percentage difference was not calculated. This review found a correlation between studies that used mobile applications approach with medium effect sizes, including Zhou et al. [73] (ES=0.57) Chao et al. [82], (ES=0.58), Anzaldo et al. [44] (ES=0.64). Three studies that used text messages had lower effect sizes, including Peimani et al. [63] (ES=0.28) Huo et al. [53] (ES=0.36) and Goodarzi et al. [51] (ES=0.40). The highest effect size (ES=1.16) in this review was reported by Dong et al. [47], a study that used a text messaging platform (WeChat). Studies that used wearable devices had mixed effect sizes, with Li et al. [56] reporting the least effect size (ES=0.12), while Sun et al. [70] had a medium effect size (ES=0.46).
Table 4: Summary of Study Effects Size for HbA1c (%)

| Study              | mHealth Mode of delivery | Control | Study Duration (Months) | Pre-intervention | Post-intervention | p-value | Intervention | Pre-intervention | Post-intervention | % Pre-Post Intervention Difference | Effect Size | Cohen's d | Hedge's g |
|--------------------|--------------------------|---------|-------------------------|-----------------|-------------------|---------|--------------|-----------------|-------------------|-------------------------------|-------------|-----------|-----------|
|                     |                          | n       | Mean        | SD   | Mean        | SD   | n            | Mean        | SD   | Mean        | SD   |                              |             |           |            |
| Anzaldo et al. [49] | Mobile App               | 10      | 100         | 1090 | 2.02       | 10.60 | 3.29         | 201          | 11.29 | 2.28       | 8.46 | 3.31                      | 2.83         | 0.64      | 0.64      |
| Chao et al. [46]    | Mobile App               | 18      | 48          | 895  | 2.34       | 782  | 1.87         | 49            | 8.44  | 2.28       | 6.92 | 1.27                      | 1.52         | 0.58      | 0.58      |
| Dong et al. [47]    | MPTMs, Int               | 12      | 59          | 923  | 2.13       | 835  | 1.75         | 60            | 9.55  | 2.38       | 6.63 | 1.17                      | 2.92         | 1.16      | 1.16      |
| Goodarzi et al. [51]| MPTMs, Uni               | 3       | 38          | 791  | 1.24       | 702  | 1.02         | 43            | 7.83  | 1.12       | 7.48 | 1.26                      | 0.36         | 0.40      | 0.40      |
| Huo et al. [53]     | MPTMs Int                | 6       | 251         | 690  | 1.40       | 6.70 | 1.30         | 251           | 7.10  | 1.40       | 7.20 | 1.50                      | 0.10         | 0.36      | 0.36      |
| Li et al. [56]      | Mobile App               | 3       | 41          | 750  | 1.80       | 6.80 | 1.33         | 44            | 7.20  | 1.8        | 6.65 | 1.08                      | 0.55         | 0.12      | 0.12      |
| Peimani et al. [63]| MPTMs, Uni               | 3       | 50          | 741  | 1.40       | 7.16 | 1.31         | 50            | 7.52  | 1.49       | 7.55 | 1.44                      | 0.90         | 0.28      | 0.28      |
| Pichayapinyo et al. [64] | MPCs                    | 3       | 35          | NR   | NR         | NR   | NR           | NR            | NR    | NR         | NR   | NR                       | NR          | NR        | NR        |
| Shahid et al. [68]  | MPCs                     | 6       | 220         | 985  | 1.37       | 9.36 | 1.15         | 220           | 10.09 | 1.71       | 8.63 | 1.29                      | 1.46         | 0.15      | 0.15      |
| Sun et al. [70]     | Mobile APPs WPMDs        | 6       | 44          | 784  | 0.73       | 684  | 0.76         | 47            | 7.88  | 0.64       | 7.22 | 0.87                      | 0.66         | 0.47      | 0.46      |
| Wang et al. [71]    | Mobile App               | 6       | 60          | 868  | 2.26       | 7.26 | 1.85         | 60            | 8.62  | 2.33       | 7.12 | 1.50                      | 0.15         | 0.38      | 0.38      |
| Zhou et al. [73]    | Mobile App               | 3       | 50          | 986  | 2.38       | 7.91 | 1.58         | 50            | 9.76  | 2.51       | 8.97 | 2.08                      | 0.79         | 0.57      | 0.57      |

1 Combined means and SD study had two intervention arms; 2 Reported effect size, interquartile range IQR; 3 NR: Not reported; WPMDs: Wearable or portable monitoring devices; MPCs: Mobile phone calls (MPCs), MPTMs: Mobile phone text messages; Uni: Unidirectional; Int: Interactive
Table 5  Summary of Study Effects Size for Fasting Blood Glucose (mg/dL)

| Study                  | Study Duration (Months) | Control mHealth mode of delivery | Pre-intervention | Post-intervention | Intervention | Pre-intervention | Post-intervention | Effect Size |
|------------------------|-------------------------|---------------------------------|------------------|-------------------|--------------|------------------|-------------------|-------------|
|                        |                         | n                               | Mean      | SD    | Mean      | SD    | p-value | n | Mean      | SD    | Mean      | SD    | Cohen's d | Hedge's g |
| Dong et al. [47]       | 12                      | MPTMs, Int                       | 59        | 164.7| 46.46     | 134.9| 42.01   | 0.01 | 60        | 173.7| 89.64     | 131.9| 28.44     | 0.08 | 0.08      |
| Goodarzi et al. [51]   | 3                       | MPTMs, Uni                       | 43        | 151.47| 55.59     | 142.00| 38.00   | 0.23 | 38        | 161.49| 54.15     | 133.56| 36.44     | 0.23 | 0.23      |
| Huo et al. [53]        | 6                       | MPTMs, Int                       | 251       | 153.15| 54.05     | 154.95| 59.46   | 0.01 | 251       | 145.95| 48.65     | 135.14| 48.65     | 0.36 | 0.36      |
| Kumar et al. [55]      | 12                      | MPTMs, Uni                       | 476       | 150.50| 62.30     | 149.20| 71.40   | 0.05 | 479       | 163.70| 66.90     | 152.80| 66.90     | 0.01 | 0.01      |
| Peimani et al. [63]    | 3                       | MPTMs, Uni                       | 50        | 166.94| 67.52     | 165.32| 57.85   | 0.04 | 50        | 170.99| 70.46     | 150.18| 66.08     | 0.24 | 0.24      |
| Rasoul et al. [66]     | 5                       | Telemedicine                     | 49        | 252.06| 39.58     | 238.24| 40.01   | 0.0001| 49        | 250.26| 50.55     | 131.08| 160.4     | 0.04 | 0.04      |
| Sun et al. [70]        | 6                       | Mobile Apps                     | 47        | 140.18| 33.33     | 130.45| 44.86   | 0.96 | 44        | 144.14| 45.77     | 130.81| 39.10     | 0.01 | 0.01      |
| Wang et al. [71]       | 6                       | Mobile APPs                     | 60        | 165.84| 74.9      | 143.32| 65.3    | 0.096| 60        | 169.4 | 77.8      | 118.4 | 54.4      | 0.41 | 0.41      |
| Zhou et al. [73]       | 3                       | Mobile APPs                     | 50        | 160.18| 52.07     | 144.50| 39.82   | 0.01 | 50        | 158.92| 9.73      | 124.68| 25.05     | 0.60 | 0.60      |

1 Combined means and SD: Study had two intervention arms; WPMDs: Wearable or portable monitoring devices; MCPs: Mobile phone calls (MPCs), MPTMs: mobile phone text message, Uni: Unidirectional; Int: Interactive
Additionally, studies that had longer durations of the intervention [44, 46, 47] had higher effect size and percentage difference (2.83, 1.52 and 2.92) between the intervention group and the comparison group. Table 5 shows FBG as reported in 9 studies [47, 51, 53, 55, 63, 66, 70, 71, 73]. In summary, this review revealed a small effect size for FBG in eight out of the nine studies. The highest effect size for FBG was reported by Zhou et al. [73] with a medium effect (Cohen’s d = 0.60). Two studies [47, 55] had longer intervention durations had lower effect size (Cohen’s d 0.08 and 0.01) for FBG.

Patient-centred Implementation outcomes

Acceptability of mHealth

Acceptability was reported in nine studies [52, 53, 57, 58, 61, 62, 65, 70]. Three studies [52, 53, 61] reported acceptability as the users’ preferred time to receive text messages. Chao et al. [46] conducted a pre- and post-interventional assessments and used the interactive personalized management framework mobile application to assess the participants mental readiness to change behaviour. Fottrell et al. [49] used small group discussions prior to all interviews involving men and women attendees and with non-attenders to get consensus on desired community changes. Table 6 below describes various aspects of user-satisfaction reported in these studies. Most of the studies that assessed and reported on user-satisfaction provided scanty details on the findings.

Only two studies in this review [53, 61] assessed the usefulness of the messages with 94.1% and 97.1% of the participants respectively. Two studies [52, 53] showed that 90.5% and 97.1% of the participants respectively, found the content of the intervention to be understandable. In general, only three studies had included measurement of acceptability as a secondary outcome. Five [52, 53, 58, 61, 70] of the nine studies that assessed acceptability measured the willingness to continue using the mHealth intervention after the study. Willingness to continue using mHealth after the intervention was 100% in Haddad et al. [52], 93.7% in Huo et al. [53], 98.0% in Limaye et al. [58], 95.9% in Owolabi et al. [61]. In Limaye et al. [58], 96% of the participants also acknowledged willingness to recommend the intervention to friends.

Feasibility of mHealth interventions

Feasibility of mHealth intervention was examined by the application of any DSMES. Table 7 below summarizes the DSMES applied in the studies. In summary, the most applied DSMES was healthy eating, in 26 studies (86.7%) and physical activity, in 24 studies (80.0%). The most applied combination of DSMES was healthy eating, physical activity, and medication usage, applied in 26, 24 and 23 studies respectively.

Appropriateness of mHealth interventions

Hermes et al. [91] describes objective measurement of appropriateness to be the perceived interventional technology fit with the specific context. Seven studies reported appropriateness variedly. As illustrated in Table 8 below.

Cost of mHealth interventions

Four studies [49, 52, 53, 58] analysed the cost of the mHealth intervention (Table 9). Various aspects of cost were reported targeting the patient, the program, or the general population.

Sustainability of mHealth intervention

As shown in Table 10 below, only two studies reported on sustainability of the mHealth interventions [58, 70]

Discussion

This systematic review found clinically significant effectiveness of mHealth interventions on HbA1c in most interventions for type 2 diabetes in LMICs. Ten out of 12 studies had a >0.3% difference for HbA1c between the mHealth intervention group and comparison group. There was however low effectiveness of mHealth on FBG in most interventions, with 8 out of 9 studies that reported FBG showing an effect size of <0.05. Mobile phone text messages (MPTMs) and mobile apps was the most common mHealth approach in 19 and 10 out of 30 studies respectively. Voice calls and wearable devices were used in five and two studies respectively. Despite the popularity of MPTMs in most interventions in our review, this mode of mHealth was associated with lower effectiveness on HbA1c and FBG. Among the patient centered outcomes, feasibility, based on DSMES domains was reported in all studies. There was substantial heterogeneity in reporting of acceptability, appropriateness, cost, and sustainability.

A change of 0.3% (3 mmol/mol) in HbA1c denotes a clinically significant margin and is generally considered to be an acceptable change [92]. Although this change seems to be relatively small, this difference in HbA1c has been associated with clinically significant effects, including reduction in the risk to diabetic complications, lower long-term risk to microvascular complications and all-cause mortality [92–94]. Despite the heterogeneity, our findings indicate that mHealth can be an effective tool to improve HbA1c. On the contrary, studies in this review revealed low effectiveness of mHealth on FBG. These findings concur with a recent metanalysis consisting of nine studies drawn from LMICs and high-income countries that reported a pooled effect size of −0.39; (P <.001) despite the different populations targeted [95]. FBG is known to be affected by numerous factors, that could be
attributable to the low effectiveness found in our review [96]. Another interesting finding from this review is that studies with intervention durations of >10 months had a higher percentage change on HbA1c compared to those conducted for shorter periods of time. On the contrary, longer durations were associated with lower effect size for FBG. Longer interventions have been associated with increased engagement, and effectiveness of mHealth interventions [97]. The reasons for the lower effect sizes for FBG are unclear, but could equally be linked with intervening factors that cannot be controlled during the interventions [96].

Patient-centered implementation outcomes included in this review were acceptability, appropriateness, feasibility, cost, and sustainability. Acceptability is associated with user-satisfaction [98]. Studies in our review hardly reported on most patient centered outcomes. Reporting of these outcomes was also widely varied. None of the studies in this review applied the mHealth evidence reporting and assessment (mERA) guidelines [99] in reporting its findings. mERA guidelines provide a criteria to identify minimum sets of information needed to the define the mHealth intervention, where it is implemented, and how it is implemented to facilitate a possible replication of an intervention. mERA guidelines recommend that interventions report on appropriateness of the interventions, user opinions on content or user interface, perceptions about usability, access, cost assessment and connectivity. This review showed that only 4 out of the 30 studies (13.3%) reported on the cost aspects of the intervention. Further, six studies reported on various aspects of appropriateness including assessments on appropriate timing of messages, satisfaction, and convenience of the intervention. In this review, we described feasibility of the intervention based on the DSMES domain applied. Three DSMES domains, including healthy eating, physical activity, and medication usage in this review were associated with a difference of >0.3% for HbA1c. Similar findings have been reported in a review or reviews that linked

Table 6: Acceptability of mHealth Interventions

| Study            | MHealth intervention | Proportion of respondents | General perceived satisfaction rate | Messages/content was understandable | Willingness to continue using the mHealth intervention |
|------------------|----------------------|---------------------------|------------------------------------|------------------------------------|-------------------------------------------------------|
| Haddad et al.    | Text messaging       | End of intervention: Questionnaire survey | 100%                               | 100%                               | 90.5%                                                 | 100%                                                 |
| Huo et al.       | Text Messaging       | Last follow-up visit acceptability and utility survey | 239 (96.8%)                        | NR                                 | 97.1%                                                 | 93.7%                                                 |
| Li et al.        | Mobile app Wearable Activity Trackers | End of intervention: 5-point Likert scale Acceptability questionnaire | 100%                               | Intervention: 45.2% Control: 40.4% |                                                        |                                                       |
| Limaye et al.    | Text Messaging, email, Website, Facebook | End of intervention: Text messages and Facebook or website | NR                                 | NR                                 | NR                                                    | 98.0%                                                 |
| Owolabi et al.   | Text Messaging       | Post-intervention: Questionnaire Survey | 98 (90.7%)                         | 98%                                | NR                                                    | 95.9%                                                 |
| Patnaik et al.   | Mobile app           | Post-intervention: Mobile Questionnaire Survey | Diet satisfaction: 3.21 ± 1.02 Treatment satisfaction: 13.09 ± 1.01 |                                    |                                                       |                                                       |
| Pfammater et al. | Text Messaging       | End of intervention: Telephone survey | Intervention: 611 (62.2%) Control: 632 (67.0%) | NR                                 | NR                                                    | NR                                                    |
| Sun et al.       | Mobile app           | End of intervention Likert scale | 100%                               | 90% (6.3/7)                        | NR                                                    |                                                       |
| Zhou et al.      | Mobile app           | Pre- and post-intervention App-based question | NR                                 | 84%                                | NR                                                    |                                                       |

*a Assessment of users’ satisfaction only included participants in the intervention arm; b Rating based on a 7-scale Likert score; c Total score: 5; d Total Score: 15
the application of technology enabled DSME domains to significantly improve HbA1c [100]. Additionally, Muller et al. [101] found that mHealth interventions can be effective in promoting physical activity and healthy diets in low income settings.

**Strengths and limitations**

This review has the strength that we used clearly defined inclusion and exclusion criteria and conducted searches in two phases. However, this review has some limitations. First, most studies in this review did not report on HbA1c, which is considered as the gold standard clinical outcome in diabetes care. Secondly, patient centered implementation outcomes are mainly reported in grey literature, which were not included in our review. Thirdly, most of the studies in this review did not apply the mERA guidelines, hence reducing replication of the intervention. Finally, we only included articles published in the English language, which introduced the language bias.

### Table 7  DSMES domains applied in mHealth interventions

| Study                   | DSMES Domains          |
|-------------------------|------------------------|
|                         | 1. Diabetes pathophysiology and treatment options | 2. Healthy eating | 3. Physical activity | 4. Medication usage | 5. Monitoring and usage of patient generated health data | 6. Preventing, detection and treatment of acute and chronic complications | 7. Healthy coping with psychosocial issues | 8. Problem solving |
| Anzaldo et al. [44]     | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Chai et al. [45]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Chao et al. [46]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Dong et al. [47]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Doocy et al. [48]       | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Fottrell et al. [49]    | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Gunawardena et al. [50] | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Goodarzi et al. [51]    | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Haddad et al. [52]      | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Huo et al. [53]         | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Islam et al. [54]       | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Kumar et al. [55]       | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Li et al. [56]          | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Liao et al. [57]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Limaye et al. [58]      | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Olmen et al. [59]       | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Owolabi et al. [60]     | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Owolabi et al. [61]     | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Patnaik et al. [62]     | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Peimanian et al. [63]   | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Pichayapinyo et al. [64]| •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Pfammatter et al. [65]  | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Rasoul et al. [66]      | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Rotheram-Borus et al. [67]| •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Shahid et al. [68]      | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Steinman et al. [69]    | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Sun et al. [70]         | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Wang et al. [71]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Yasmin et al. [72]      | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
| Zhou et al. [73]        | •                      | •                      | •                      | •                      | •                      | •                      | •                      | •                      |
### Conclusion

mHealth interventions in LMICs are associated with clinically significant effectiveness on HbA1c but have low effectiveness on FBG. Interventions applying mobile apps have a high effect size on HbA1c compared to those that apply text messaging, voice calls or wearable devices. Percentage changes of >0.3% in HbA1c was correlated with three DSMES domains, including healthy eating, physical activity, and medication adherence. These findings suggest that mobile apps may be a promising tool for diabetes management in LMICs, especially when targeting intensive behavioral change.

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**Table 8** Appropriateness of mHealth Interventions

| Study          | MHealth intervention          | Messages/ content was understandable | Measures of appropriateness                                                                 |
|----------------|------------------------------|--------------------------------------|-------------------------------------------------------------------------------------------|
| Haddad et al.  | Text messaging               | 90.5%                                | • Received messages at appropriate times: 100%                                            |
| Huo et al.     | Text Messaging               | 97.1%                                | • Text messaging useful: 94.1%                                                             |
| Limaye et al.  | Text Messaging, email, Website, Facebook® | NR                                   | • Recommend approach to family or friends: 96%                                            |
| Owolabi et al. | Text Messaging               | NR                                   | • Average adherence at 1 year: 74.5%                                                      |
| Patnaik et al. | Mobile application           | NR                                   | • Average e-mail opening rate at 6 months: 93%                                            |
| Sun et al.     | mHealth management app       | NR                                   | • Treatment satisfaction: 12.94 ± 2.9 out of total score of 15 (86.2%)                      |

**Table 9** Cost of mHealth interventions

| Study          | Cost description                                      | Cost                          | Focus            |
|----------------|-------------------------------------------------------|-------------------------------|-----------------|
| Huo et al.     | Cost per text message                                 | US$0.01                       | Patient          |
| Haddad et al.  | Cost per text message                                 | € 0.065                       | Patient          |
| Fottrell et al.| Total annual costs of the PLA intervention            | $ 601,484                     | Program          |
|                | Average annual costs of the PLA intervention          | $240,594                      | Program          |
|                | Total annual costs of mHealth intervention            | $312,630                      | Program          |
|                | Average annual costs of mHealth per beneficiary      | $14                           | Patient/ Program |
|                | Average annual costs of mHealth per beneficiary      | $7                            | Patient/ Program |
|                | Cost-effectiveness ratios for PLA per case of intermediate hyperglycaemia or type 2 diabetes | $316 ($124 per DALY averted) | Population |
|                | Cost-effectiveness ratios per case of type 2 diabetes prevented | $65,18 ($2,551 per DALY averted) | Population |
| Limaye et al.  | Annual direct medical cost per participant in the control group | £23.30                        | Patient          |
|                | Annual direct medical cost per participant in the intervention group | £35.80                        | Patient          |
|                | Incremental cost of treating or preventing one case of overweight/obesity in 1 year | £112.30                      | Patient/ Program |

**Table 10** Sustainability of mHealth Interventions

| Study          | Indicator                                      | Period of measuring Sustainability | Indicators of sustainability                                                                 |
|----------------|-----------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------------|
| Limaye et al.  | Weight, waist circumference, diastolic blood pressure | After 1 year                      | • Exercise ≥ 150 mins/week                                                                  |
|                |                                               |                                   | • Raw food Consumption ≥ 8 servings/week                                                      |
|                |                                               |                                   | • Energy Dense food consumption ≥ 4 servings/week                                              |
|                |                                               |                                   | • Awareness score ≥ 75%                                                                      |
| Sun et al.     | mHealth and eHealth intervention              | After the intervention (6 months) | • Cost of implementation and maintenance too high                                           |
|                |                                               |                                   | • Low impact shown by the study                                                               |

PLA Participatory Learning Activities
activity, and medication usage. The use of the mHealth evidence reporting and assessment (mERA) guidelines may standardize and improve reporting of patient-centered implementation outcomes in LMICs.

Implications for future research
Clinical and patient centered implementation outcomes should be considered in the planning, implementation and monitoring of mHealth interventions. This approach optimizes the individualization of care, which is vital in diabetes care. Additionally, mERA guidelines need to be applied in reporting so as to standardize and provide rigor in mHealth intervention globally.

Abbreviations
App: Application; AST: aspartate transaminase; BG: Blood Glucose; BMI: Body Mass Index; BP: Blood pressure; CONSORT: Consolidated Standards of Reporting Trials; DSMEn: Diabetes Self-Management and Education; DSMES: Diabetes self-management education and support; FBG: Fasting blood glucose; FU: follow-up; Hba1c: Glycated haemoglobin; HDL-c: High Density Lipoprotein Cholesterol; I1: First Intervention Arm; I2: Second Intervention Arm; IPMF: Interactive personalized management framework; LDL-c: Low Density Lipoprotein Cholesterol; LMICs: Low- and middle-income countries; Med: Medication; Mos: Months; NO: Not Provided; OP: Outpatient; PA: Physical Activity; PBC: Post-prandial Blood Glucose; PCHR: Personally Controlled Health Record; PICO5: Participants, interventions, comparisons and outcome(s) and study design; PRISMA:Preferred Reporting Items for Systematic reviews and Meta-Analysis; PT: Patient; QA: Question and answer; RCTs: Randomized controlled Trials; SBP: Systolic Blood pressure; SD: Standard Deviation; STROBE: Strengthening the Reporting of Observational Studies in Epidemiology; TC: Total cholesterol; TG: Triglycerides; Wk: Week; Wt: Weight.

Supplementary Information
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Additional file 1.
Additional file 2.
Additional file 3.

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Authors’ contributions
MM developed the protocol in collaboration with CM and FK. MM carried out the search, analyzed and wrote the manuscript. CM and FK were major contributors in writing the manuscript. RV interpreted the data from a clinical point of view. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article [and its supplementary information files].

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