

# Effectiveness of mobile applications in diabetic patients' healthy lifestyles: review of systematic reviews.

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## Systematic Review

**Keywords:** Diabetes Mellitus, Systematic Review, Life Style, Mobile Applications

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## Abstract

**Background:** Diabetes mellitus (DM) is currently a major public health problem worldwide. It is traditionally approached by a clinical inpatient relationship between patients and healthcare professionals. However, the rise in of the use of new technologies, particularly mobile applications, is revolutionizing the traditional healthcare model with the introduction of telehealthcare.

**Objective:** (1) Examine the mobile applications that address lifestyles to improve the metabolic control of adult patients with Diabetes Mellitus. (2) Describe the characteristics of the used mobile applications, identify the healthy lifestyles they target, and describe any of their adverse effects.

**Methods:** Review of systematic reviews following Cochrane Collaboration and Joanna Briggs Institute guidelines. We included studies that used any mobile application to help patients improve DM self-management by focusing on healthy lifestyles. Studies needed to include a control group receiving regular care without using mobile devices. In May 2018, Medline, Embase, Cochrane, LILACS, PsychINFO, Cinahl and Science Direct were searched, updated in May 2019. The methodological quality of the studies was assessed by the Amstar-2 tool.

**Results:** Seven systematic reviews of 798 articles were initially selected for the analysis. Interventions lasted 1-12 months. Twenty-three different mobile applications were identified. They were all related to eating and physical activity. Significant changes were found in HbA1c values, body weight and BMI, but no clear improvement was observed in others like lipid profile, quality of life or blood pressure. No significant adverse effects were identified.

**Conclusions:** Clearly evidence appeared for using mobile applications to improve glycemic control in diabetic patients in the short term, but not for long-term benefits. Thus carrying out further studies is necessary to learn about the long-term effectiveness of mobile applications to promote DM patients' healthy lifestyles.

**PROSPERO Register:** CRD42019133685

## Introduction

The International Diabetes Federation (IDF) estimates some 425 million people diagnosed with diabetes mellitus (DM) worldwide, whose prevalence will rise to 693 million by 2045 [1]. It is well-known that DM significantly increases cardiovascular risk and is usually associated with unhealthy lifestyle; e.g. being overweight, obesity, smoking, unbalanced diet, sedentary lifestyle [2,3]. For these reasons, DM is currently a major public health problem worldwide [4].

The rapid progress in information technology in recent years has enabled the creation of software extensions, popularly known as mobile applications (Apps), that users can add to their mobile devices (Apps). These tools are being increasingly employed to manage different health matters. In 2018, more than 100,000 such applications were available to make users' health self-care easier [5].

The main aim of treating DM is to prevent or delay the onset of microvascular and macrovascular complications due to suitable metabolic control, where practicing healthy lifestyles is fundamental [6]. This therapeutic objective has been dealt with in the conventional health context by the doctor-patient relationship. At present, the mobile apps used for the same purpose are revolutionizing this traditional care model.

Given the substantial progress made in recent years in non face-to-face healthcare, in 2011 the World Health Organization (WHO) defined the "*m-health*" concept as the practice of medicine and public health supported by the use of mobile devices (mobile phones, patient monitoring devices, personal digital assistants and other wireless devices) [7]. Mobile systems allow the following: prevention, diagnosis and/or treatment activities also serve as a means of communication between healthcare team members, professionals and patients, and patient to patient [8].

The systematic reviews published so far about the effectiveness of Apps for promoting healthy lifestyles have yielded mixed and inconclusive results. Some reviews offer positive results [9-13], and the majority concludes that more research studies are necessary to assess their real effectiveness [14-25], while a few reviews state that these types of intervention are not effective [26,27].

Moreover, differences in facilitating elements and barriers have been described with the population using digital health platforms, which means that their accessibility and acceptability are not universal [28]. Accordingly, as part of its Action Plan on electronic health (eHealth) 2012-2020 and the Digital Agenda, the European Commission has published the "Green Paper on mobile health", with which it intends to conduct a public consultation on current obstacles and problems related to implementing mobile health to help it reach its full potential [29].

The present review uses the "DM self-control" concept defined by Powers et al. [30] as the ongoing "process of facilitating the knowledge, skills and capacity necessary for diabetes self-care". Its ultimate goal is to improve clinical outcomes, health status and patients' quality of life. It

also attempts to answer the question: are mobile applications that deal with lifestyles to improve the metabolic control of adult patients with DM effective?

In line with this question, we consider that the **main objective** is to examine mobile applications that address lifestyles to improve the metabolic control of adult patients with DM. As **secondary objectives**, we aim to describe the characteristics of the used apps, identify the healthy lifestyle aspect they target, and describe any adverse effects of their uses.

## Methods

### Design

A review of systematic reviews was performed. This design allowed us to compare and verify the findings of relevant reviews in response to similar review questions, which facilitates a view and clear understanding of a broad theme area [31]. Its main purpose is to summarize evidence from many research sources. Compared to a systematic review limited to one treatment or one intervention, this type of review offers a broader view of many interventions. It is useful for health-related technology assessments whose objective is to inform about patterns for clinical practice where many handling options must be considered and evaluated.

To implement the review, we followed the Cochrane Collaboration [32] and Reviewers Manual of the Joanna Briggs Institute [33] guidelines. To prepare this report, we took into account the PRISMA proposal [34] recommendations.

The protocol of this systematic review was registered in PROSPERO with code CRD42019133685 [35].

### Inclusion and exclusion criteria

1. Type of study: Systematic review and/or meta-analysis.
2. Population: Patients aged over 18 years diagnosed with DM regardless of the type of treatment followed.
3. Intervention: using any App to help patients improve DM self-management by a healthy lifestyles approach. The mobile application can be used exclusively or combined with other types of interventions. The study needed to describe the type of employed mobile application and the addressed lifestyle aspect. Studies in which text messages were sent via mobile phones, independently of the use of any mobile application being excluded.
4. Comparison: a control group receiving regular care without using mobile devices toward healthier lifestyles.
5. Outcome measures. Primary: Glycosylated hemoglobin (HbA1c), change in body weight or body mass index (BMI), and occurrence of/increase in adverse effects (anxiety, depression, hypoglycemia episodes, etc.). Secondary: health-related quality of life (HRQOL), systolic (SBP) and diastolic (DBP) blood pressure, fasting blood glucose, lipid profile; total cholesterol (TC), LDL cholesterol (LDL-C), HDL cholesterol (HDL-C), triglycerides (TG).

The studies that did not report any primary or secondary outcomes were excluded. Studies had to include a comparative analysis of the outcomes measured at the baseline and those measured at the end of the intervention.

### Sources of information and search strategy

To define the search strategy, we used a set of studies that was first divided to facilitate the location and definition of the main descriptors. The key terms and their synonyms were identified in the Medline (via PubMed), Cinahl and Google Scholar databases. The identified terms were combined to calibrate a search syntax in Medline by bearing the sensitivity and specificity criteria in mind.

Next a second search using all the identified keywords and index terms was performed in the following electronic databases: Medline, Embase, Cochrane, Lilacs, PsychINFO, Cinahl and Science Direct. Articles were selected in May 2018 and updated in May 2019. There were no limits in terms of language or year of publication. The syntax of the bibliographic search carried out in Medline is attached (Multimedia Appendix 1).

The search for unpublished studies was carried out in: Open Grey, ProQuest Dissertations & Theses Global, Theseo, Networked Digital Library of Theses and Dissertations (NDLTD).

Finally, the reference lists of all the identified reports and articles were searched for additional studies. The search was completed by hand searching and reverse searching in reference journals specializing in smoking, diabetes and e-health.

The Mendeley reference management software was used to sort the bibliographic citations obtained in the search to eliminate duplicate citations and to order all the studies to facilitate the analysis.

### Study Selection

The complete study selection process was carried out by peer review. In the event of disagreement between the two reviewers, a third party was invited to participate.

First, a selection of the studies was made based on their title and/or Abstract according to the predefined inclusion criteria. Duplicates and those articles which, given their title and/or Abstract did not match our field of interest, were eliminated. None of the authors of the review was blinded to the titles of journals or the authors or institutions of the study.

Second, a new selection was made by reading the full articles and verifying that they met the inclusion criteria.

### **Assessing methodological quality**

After selection, studies were assessed as to their methodological quality with the *Measurement Tool to Assess Systematic Reviews-2* (Amstar-2) [36].

Amstar-2 allows the assessment of systematic reviews, which include randomized controlled clinical trials (RCTs) and non randomized health interventions. This questionnaire consists of 16 items with several response categories: "yes", when the answer is positive; "no", when the item is not present or contains insufficient information to respond; "partial yes", when the item is partially present. Seven domains (items 2, 4, 7, 9, 11, 13 and 15) are considered critical because they can significantly affect a review's validity and conclusions. It classifies the quality of systematic reviews into four levels: high, moderate, low, very low.

This methodological quality assessment was made in pairs. Although provided for in the protocol, it was not necessary to consult a third reviewer because an agreement between reviewers was reached. We included reviews of moderate or high methodological quality in our review. Reviews with low or very low quality were excluded so as not to distort the evidence of the conclusions.

### **Data extraction and variables**

The data from the studies were extracted, synthesized and recorded on an Excel sheet which included: Amstar-2 items, first author, year, source, search strategy, number of included studies, total number of participants, study design, intervention time (months) and outcome measures.

Data were extracted independently by two reviewers. The reliability and quality of the extracted data were ensured by cross-checking, rereading the complete studies and reviewing the collected data.

### **Data analysis and synthesis**

After using the form to collect and synthesize all the relevant data, they were presented, depending on how they were reported in each case, in the form of mean, standard deviation, and/or 95% confidence interval with their statistical significance value (*P*).

Descriptive results were presented according to the following sections: characteristics and quality of studies, Apps and lifestyle they intended to modify, primary outcome measures, secondary outcome measures and adverse effects of interventions.

## **Results**

The initial bibliographic search yielded 798 articles, of which 23 duplicates were eliminated. Subsequently, 56 articles were selected for title and Abstract. After their complete reading, 39 were discarded because they did not meet the inclusion criteria. Finally, 17 articles were selected, of which 10 were discarded for their low methodological quality (Table 1). Thus the final selection included seven systematic reviews (Figure 1).

**Table 1.** Quality assessment of systematic reviews through Amstar-2

Items Amstar-2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Methodological Quality
McMillan, 2017 [13]	YES	NO	YES	YES PARTIAL	NO	NO	YES	YES	YES PARTIAL	YES	NA	NA	NO	NO	NA	YES	Low
Pal, 2013 [14]	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	High
Fu, 2017 [17]	YES	NO	YES	YES PARTIAL	NO	NO	YES PARTIAL	YES PARTIAL	NO	NO	NA	NA	NO	NO	NA	NO	Low
Porter, 2016 [27]	YES	YES PARTIAL	YES	YES PARTIAL	YES	NO	YES	YES	YES PARTIAL	NO	NA	NA	YES	YES	NA	NO	Moderate
Anderson, 2016 [37]	NO	NO	YES	YES PARTIAL	NO	NO	YES PARTIAL	YES PARTIAL	NO	NO	NA	NA	NO	NO	NA	YES	Very low
Hou, 2016 [38]	YES	NO	YES	YES PARTIAL	YES	YES	YES	YES PARTIAL	YES PARTIAL	NO	YES	YES	NO	YES	YES	NO	Baja
Cotter, 2014 [39]	NO	NO	NO	YES PARTIAL	YES	YES	YES	YES	NO	YES	NA	NA	NO	YES	NA	YES	Very low
David, 2016 [40]	NO	NO	YES	NO	NO	NO	YES	YES	NO	NO	NA	NA	NO	NO	NA	NO	Very low
Bonoto, 2017 [41]	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	Moderate
Drincic, 2016 [42]	YES	NO	YES	NO	NO	NO	NO	YES	NO	NO	NA	NA	NO	NO	NA	NO	Very low
El-Gayar, 2013 [43]	YES	NO	NO	YES PARTIAL	YES	NO	YES	YES PARTIAL	NO	NO	NA	NA	NO	NO	NA	NO	Very low
Hood, 2016 [44]	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NA	NA	NO	NO	NA	YES	Very low
Veazie, 2018 [45]	YES	NO	YES	YES PARTIAL	YES	NO	YES	YES PARTIAL	YES PARTIAL	YES	NA	NA	YES	YES	NA	YES	Moderate
Aminuddin, 2019 [46]	NO	YES	NO	YES	YES	NO	NO	YES PARTIAL	NO	YES	NO	NO	NO	NO	NO	YES	Very low
Akbari, 2019 [47]	NO	NO	YES	YES PARTIAL	YES	YES	YES PARTIAL	YES PARTIAL	YES	NO	YES	YES	YES	YES	YES	YES	Moderate
Lunde, 2018 [48]	YES	YES PARTIAL	YES	YES PARTIAL	YES	YES	YES PARTIAL	NO	YES PARTIAL	NO	YES	YES	YES	YES	YES	YES	Moderate
Wu, 2019 [49]	NO	NO	YES	YES	YES	YES	YES PARTIAL	YES PARTIAL	YES PARTIAL	YES	Moderate						

<sup>1</sup> Did the research questions and inclusion criteria for the review include the components of PICO? <sup>2</sup> Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol? <sup>3</sup> Did the review authors explain their selection of the study designs for inclusion in the review? <sup>4</sup> Did the review authors use a comprehensive literature search strategy? <sup>5</sup> Did the review authors perform study selection in duplicate? <sup>6</sup> Did the review authors perform data extraction in duplicate? <sup>7</sup> Did the review authors provide a list of excluded studies and justify the exclusions? <sup>8</sup> Did the review authors describe the included studies in adequate detail? <sup>9</sup> Did the review authors use a satisfactory technique for assessing the risk of bias in individual studies that were included in the review? <sup>10</sup> Did the review authors report on the sources of funding for the studies included in the review? <sup>11</sup> If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results? <sup>12</sup> If meta-analysis was performed, did the review authors assess the potential impact of risk of bias in individual studies on the results of the meta-analysis or other evidence synthesis? <sup>13</sup> Did the review authors account for risk of bias in individual studies when interpreting/discussing the results of the review? <sup>14</sup> Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review? <sup>15</sup> If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review? <sup>16</sup> Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?  
 NA=Not applicable.

**Characteristics and quality of the systematic reviews**

The main characteristics of the seven systematic reviews included in this review are shown in Table 2. The complete analysis of their methodological quality is found in Table 1.

Although differences were observed in search methods, databases, inclusion and exclusion criteria, data extraction, quality assessments and statistical analyses, the seven systematic reviews generally provided an extensive description of the used methods, as well as the quality and general characteristics of the studies they included.

The studies included in the seven systematic reviews were conducted mainly in the United States, Asia and Europe. When we analyzed the original studies included in the reviews, we considered that 28 studies appeared in more than one systematic review.

The number of studies included in each analyzed review fell within the 8-19 range. In all cases, except for one study with a cross design featured in the review by Porter *et al.* [27], random clinical trials (RCTs) were included which assessed interventions based on using Apps to manage DM in adult patients. Interventions lasted between 1 and 12 months. The vast majority of the studies analyzed HbA1c as the primary outcome measure, which was also used to perform a meta-analysis in the reviews by Pal *et al.* [14], Bonoto *et al.* [41], Lunde *et al.* [48] and Wu *et al.* [49].

**Table 2.** General characteristics of the included systematic reviews

First author, year / source	Search strategy	No. studies included / Total no. of participants	Objective	Population	Intervention	Comparison	Outcome measures	Time (months)	Quality
Pal, 2013 <sup>14</sup> / Cochrane Database of Syst Rev	Cochrane Library, MEDLINE, EMBASE, PsycINFO, Web of Science, CINAHL; + 3 databases for thesis Indicated search terms.  No restrictions with publishing date and language.	16 RCT / 3.578	Evaluate the effect of DM self-control interventions based on computer tools about health status and CVRS.	DM2  ≥ 18 years	Apps to help patients acquire knowledge, skills (lifestyles) and emotional self-control emotional (handling stress, anxiety and social support).	Usual healthcare	<i>Primary:</i> CVRS (N=5) HbA1c (N=16) Death by any cause (N=2)  <i>Secondary:</i> Cognitive faculties: knowledge/ comprehension (N=4); self-efficacy (N=2) Habits: physical activity (N=5); diet (N=6) Social help (N=2) PAS and PAD (N=5) Lipid profile (N=10) BMI/kg (N=5) Anxiety or depression (N=6) Complications (N=0) Adverse effects (N=1)	1-12	High
Porter, 2016 <sup>27</sup> / Nutrients	Ovid MEDLINE, EMBASE, CINAHL, EBM Reviews Cochrane Database of Systematic Reviews, PsycINFO, EBM Reviews-Health Technology Assessment.  Indicated search terms.  No restrictions with publishing date and language.	9 (N=8 RCT + N=1 Crossed) / 1.234	Determine the effect of using Apps designed to record the intake of food or nutrients on controlling DM and nutritional outcomes.	DM1 DM2  ≥ 18 years	Apps for recording food intake, glycemia, physical activity and medication.	Usual healthcare	<i>Primary:</i> HbA1c (N=9)  <i>Secondary:</i> Glycemia on an empty stomach (N=4) BMI/kg/anthropometry (N=6) Lipid profile (N=5) Diet (N=2) Satisfaction and usefulness (N=4) Acceptance and commitment (N=5)	3-12	Moderate
Bonoto, 2017 <sup>41</sup> / JMIR Mhealth Uhealth	MEDLINE, Cochrane Library (CENTRAL), LILACS.  Indicated search terms.  Publishing date 2008-2016.  No language restrictions.	13 RCT / 1.263	Evaluate the effectiveness of Apps as a healthcare support.	DM1 DM2  ≥ 18 years	Apps that works as an automatic reminder to help adhere to DM self-control measures (glycemia, weight, medication, food, physical activity).	Usual healthcare	<i>Primary:</i> HbA1c (N=12) Hypoglycemia episodes (N=5)  <i>Secondary:</i> Glycemia on an empty stomach (N=4) Body weight (N=6) SBP and DBP (N=4) Lipid profile (N=3) Quality of life/satisfaction (N=6)	1-12	Moderate
Veazie, 2018 <sup>45</sup> / J Gen Intern Med	Ovid MEDLINE, Cochrane Database of Systematic Reviews.  No indicated search terms.  Publishing date January 2008-June 2017.  Restricted to the English language.	15 (N=13 RCT + N=2 Subgroup RCT) / ne	Examine the characteristics, clinical efficacy and usability of Apps for DM self-management	DM1 DM2  ≥ 18 years	Apps to improve diabetes self-control (social support, education, reminder of activities, recording glycemia, medication, patient-professional communication).	Usual healthcare	<i>Primary:</i> HbA1c Hypo/hyperglycemia episodes Glycemia on an empty stomach BP Lipid profile BMI/kg/anthropometry Diabetic symptoms Quality of life Stress/depression Satisfaction and usefulness Self-care and self-efficacy	2,5-12	Moderate

Akbari, 2019 <sup>47</sup> / Diabetes Metab Syndr	PubMed, EMBASE, Web of Science, Cochrane Library Databases.  Indicated search terms.  No restrictions with publishing date and language.  No publishing date restrictions	9 RCT / 997	Evaluate the effect of “m-health” on the lipid profile of patients with metabolic syndrome and obesity, DM or heart disease	DM1 DM2  ≥ 18 years	Apps to improve the lipid profile through healthy life habits (physical activity, food, emotional support, medication, smoking).	Usual healthcare	<i>Primary:</i> Lipid profile	3-12	Moderate
Lunde, 2018 <sup>48</sup> / J Med Internet Res	EMBASE, MEDLINE, CINAHL, Academic Research Premier, Cochrane Reviews and Trials.  Indicated search terms.  Publishing date before 23/02/17.  Restricted to the English language.	8 RCT / 1.201	Revise the effectiveness of interventions based on Apps that lasted a minimum of 3 months to promote changes in lifestyles.	DM1 DM2  ≥ 18 years	Apps to monitor glycemia, BP and/or diet habits	Usual healthcare	<i>Primary:</i> HbA1c (N=8) BMI/kg (N=6) Abdominal girth (N=3) Quality of life (N=3) Habits: physical activity (N=1); diet (N=1)	3-12	Moderate
Wu, 2019 <sup>49</sup> / JMIR Mhealth Uhealth	Cochrane Central Register of Controlled Trials in the Cochrane Library, MEDLINE, EMBASE, CINAHL, PsycINFO.  Indicated search terms.  Publishing date 01/01/06-14/05/18.  No language restrictions	19 RCT / 1.605	Summarize existing clinical evidence for the efficiency of Apps to modify lifestyles in different DM types.	DM1 DM2  ≥ 18 years	Apps to help to improve lifestyles (physical activity, food, medication, education).	Usual healthcare	<i>Primary:</i> HbA1c (N=16)  <i>Secondary:</i> Lipid profile (N=7) SBP and DBP (N=10) Change in treatment (N=3) Anxiety or depression (N=4) BMI/kg (N=11) Quality of life/satisfaction (N=5) Knowledge/self-care (N=9) Abdominal girth (N=7) Habits: physical activity (N=6); diet (N=2) Complications (N=1)	3-12	Moderate

No: Number / DM1: Type 1 Diabetes Mellitus / DM2: Type 2 Diabetes Mellitus 2 / ns: Not specified / RCT: random clinical trial / BP: Blood pressure / SDP: systolic blood pressure / DBP: diastolic blood pressure / BMI: body mass index / HbA1c: glycated hemoglobin / kg: Kilograms of body weight / HRQOL: health-related quality of life.

### Mobile applications and the lifestyles they address

The identified mobile Apps and lifestyles are provided in detail in Table 3.

Twenty-three different apps were identified. The only App that was included in all seven systematic reviews was “BlueStar Diabetes”, which offers free access for Apple and Android, and addresses food. We were unable to identify the commercial name of one App.

Regarding the lifestyles covered by Apps, eight included different questions about DM self-control in relation to food, five to physical activity, and 10 combined both these components.

Most research into the effectiveness of Apps was conducted with individuals with DM2. Although their effectiveness for DM1 was also studied, no systematic reviews included studies about Gestational Diabetes (GD).

**Table 3.** The mobile applications included and the lifestyles they address

App	Systematic Review	Operating system	DM type	Lifestyle	Cost
Bees	Veazie, 2018 <sup>45</sup>	Apple/Android	DM1	Physical activity and food	Free
BlueStar Diabetes	Pal, 2013 <sup>14</sup> / Porter, 2016 <sup>27</sup> / Bonoto, 2017 <sup>41</sup> / Veazie, 2018 <sup>45</sup> / Akbari, 2019 <sup>47</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	Apple/Android	DM2	Food	Free
CollaboRhythm	Bonoto, 2017 <sup>41</sup>	ns	DM2	Physical activity and food	ns
Connected Wellness Platform	Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	Android	DM2	Physical activity and food	ns
Diabeo Telesage	Bonoto, 2017 <sup>41</sup> / Veazie, 2018 <sup>45</sup> / Wu, 2019 <sup>49</sup>	Apple/Android	DM1	Physical activity and food	Free
Diabetes Diary	Veazie, 2018 <sup>45</sup> / Wu, 2019 <sup>49</sup>	Apple/Android	DM1	Food	Free
Diabetes diet advisor	Pal, 2013 <sup>14</sup>	ns	DM2	Food	ns
Diabetes Interactive Diary (DID)	Porter, 2016 <sup>27</sup> / Bonoto, 2017 <sup>41</sup> / Veazie, 2018 <sup>45</sup> / Akbari, 2019 <sup>47</sup> / Wu, 2019 <sup>49</sup>	Android	DM1	Food	Free
Diabetes Pilot™	Porter, 2016 <sup>27</sup>	Apple	DM2	Food	Payment
Diabetes Under Control (DBEES)	Bonoto, 2017 <sup>41</sup> / Porter, 2016 <sup>27</sup>	Apple/Android	DM1	Physical activity and food	Free
DialBetics	Porter, 2016 <sup>27</sup> / Akbari, 2019 <sup>47</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	ns	DM2	Physical activity and food	ns
eCoFit	Wu, 2019 <sup>49</sup>	Android	DM2	Physical activity	Free
Few Touch Application (FTA)	Bonoto, 2017 <sup>41</sup> / Porter, 2016 <sup>27</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	ns	DM2	Physical activity and food	ns
FoodLog	Porter, 2016 <sup>27</sup> / Akbari, 2019 <sup>47</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	ns	DM2	Physical activity and food	ns
Gather Health	Veazie, 2018 <sup>45</sup>	Apple/Android	DM2	Physical activity and food	Free
Glucose Buddy	Bonoto, 2017 <sup>41</sup> / Veazie, 2018 <sup>45</sup> / Wu, 2019 <sup>49</sup>	Apple/Android	DM1	Physical activity and food	Free
LiFe!	Wu, 2019 <sup>49</sup>	Android	DM2	Physical activity	Free
mDiab	Veazie, 2018 <sup>45</sup>	Apple/Android	DM2	Physical activity	Payment
METADIETA	Bonoto, 2017 <sup>41</sup>	Apple/Android	DM2	Food	Payment
Monica	Bonoto, 2017 <sup>41</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	Android	DM2	Physical activity	ns
NICHE	Wu, 2019 <sup>49</sup>	ns	DM2	Physical activity	Free
WellTang	Porter, 2016 <sup>27</sup> / Veazie, 2018 <sup>45</sup> / Akbari, 2019 <sup>47</sup> / Lunde, 2018 <sup>48</sup> / Wu, 2019 <sup>49</sup>	Apple	DM1/DM2	Food	Free
ne	Wu, 2019 <sup>49</sup>	ns	DM2	Food	ns

App: Mobile Application / DM1: Type 1 Diabetes Mellitus / DM2: Type 2 Diabetes / ns: Not specified

### Primary outcome measures

Pal *et al.* [14] performed a meta-analysis of the 11 studies, which provided sufficient data on HbA1c levels. They found statistically significant differences between the results of the intervention groups and the control groups, with lower HbA1c values in the intervention subjects. The impact of the intervention was significantly stronger ( $P < .001$ ) in the three studies that used mobile phones, with an effect on HbA1c of -5,5 mmol/mol or -0.5% (95%CI: -0.74 to -0.26;  $P = .59$ ;  $I^2 = 0\%$ ). However, the effects of interventions seemed to disappear with time as the analysis of the results of the studies with a duration equal to or longer than 6 months was not statistically significant.

In four of the nine studies they analyzed, Porter *et al.* [27] found a statistically significant improvement in HbA1c of diabetics in the intervention group compared to the control group, while the other studies observed no significant differences between the two groups.

In the review by Bonoto *et al.* [41], in six of the 12 studies that included HbA1c values, a statistically significant difference was found in the reduction of this parameter in favor of intervention groups. Likewise, the meta-analysis carried out in this review showed the effectiveness of using mobile applications to control diabetes, with an average difference of -0.44% (95%CI: 0.59 to -0.29;  $P < .10$ ;  $I^2 = 32\%$ ), which was statistically significant ( $P < .001$ ).

Veazie *et al.* [45] identified two Apps to control DM1 (*Glucose Buddy* and *Diabeo Telesage*) and three others for DM2 (*Gather Health*, *BlueStar* and *WellTang*), whose use demonstrated better statistics and clinical significance for HbA1c than the control groups (CG).

Lunde *et al.* [48] included three studies to evaluate the effectiveness of short-term apps, and four long-term studies. The result was a significant decrease in HbA1c in both cases, although the quality of the evidence was poor for the short-term and moderate for the long-term Apps.

However, Wu *et al.* [49] did not reveal any significant difference in HbA1c between the intervention group and control group with DM1, in both the short -0.09% (95%CI: 0.34 to -0.15;  $P = .18$ ;  $I^2 = 39\%$ ) and long term -0.21% (95%CI: -0.52 to -0.09;  $P = .17$ ;  $I^2 = 64\%$ ) terms. In the Apps that addressed patients with DM2, a statistically significant difference appeared in both the short and long terms with 0.35% (95% CI: -0.48 to -0.21;  $P < 0.01$ ;  $I^2 = 0\%$ ).

To assess the effect of interventions based on using Apps on diabetic patients' healthy lifestyles, we also analyzed changes in body weight or BMI as a result of the intervention. Lunde *et al.* [48], included three studies in which the IG reduced weight significantly [50-52]. In the review by Pal *et al.* [14], only two of the five studies using mobile devices in their interventions reported changes in body weight and BMI [51,54]. However, these authors found no significant differences between the intervention groups and control groups. Bonoto *et al.* [41] did not observe any significant differences in their combined analysis of the results of four studies with data on changes in participants' body weight [mean difference: -0.39 (95%CI: -1.43 to 0.66;  $P = .47$ ;  $I^2 = 0\%$ )]. Similarly in their review, Porter *et al.* [27] described that none of the six studies with body weight or BMI data found significant changes linked with the intervention. Only one study indicated a slight reduction in the BMI of all the groups, but did not provide any data [53]. Finally, none of the participants in the studies analyzed by Veazie *et al.* [45] reported improvements in body weight or BMI.

## Secondary Outcome Measures

Health-related quality of life (HRQL) was analyzed as a secondary outcome measure of interventions based on the use of Apps. Of the 16 studies included in the review by Pal *et al.* [14], five provided results on HRQL. However, these authors did not observe any significant improvement in the HRQL of the intervention subjects compared to the control subjects. Bonoto *et al.* [41] found that three studies yielded positive and statistically significant changes in both the quality of life of and satisfaction with the treatment of the patients in the intervention group. The improvements reported by the participants using Apps included perceiving hyperglycemia episodes, social relationships, feeling less fear of hypoglycemia and that Apps helped them to control their treatment and to maintain healthier dietary habits [54-56]. Conversely, Veazie *et al.* [45] found no evidence for improvement in the quality of life of the diabetic patients who used mobile Apps.

Some of the studies included in the seven analyzed reviews provided results on the lipid profile of diabetic subjects, which may be related to changes in their dietary habits and lifestyles. In connection with this, Pal *et al.* [14] carried out a meta-analysis with data from seven studies and found that the effect of the intervention on the participants' lipid profile was not significant ( $P = .17$ ), with a mean difference to the control group of -0.11 (95%CI: -0.28 to 0.05;  $P = .03$ ;  $I^2 = 57\%$ ). A significant improvement in the lipid profile was observed in only one intervention study based on using mobile devices, specifically a reduction in TC, LDL-C and TG levels. Bonoto *et al.* [41] and Akbari *et al.* [47] also found no significant differences in their meta-analysis of TC, HDL-C, LDL-C and TG levels. Porter *et al.* [27] and Veazie *et al.* [45] identified one study which observed a significant lowering ( $P = .04$ ) of triglyceride levels, but not the remaining lipids, in the participants who used a mobile app to control DM1 (*Diabetes Interactive Diary*) [55].

Regarding changes in diabetic patients' blood pressure, one study included in the review by Pal *et al.* [14] found a statistically significant decrease in SBP ( $127 \pm 14$  mmHg to  $120 \pm 19$  mmHg;  $P = .001$ ) and DBP ( $78 \pm 10$  mmHg to  $74 \pm 8$  mmHg,  $P < .001$ ) in the intervention group [57]. Bonoto *et al.* [41] did not observe any significant differences for the intervention and control groups of four studies in participants' SBP and DBP. Similarly, no intervention analyzed in the review by Veazie *et al.* [45] revealed participants' improved blood pressure.

Finally in a combined analysis of fasting blood glucose results from four studies, Bonoto *et al.* [41] reported no significant differences between the intervention and control groups. In the review by Porter *et al.* [27], two studies described a significantly more marked reduction ( $P < .01$ ) in fasting blood glucose levels for the intervention group than for the control group [56,59], while two other studies did not observe any significant differences between these two groups [56,58]. Veazie *et al.* [45] identified one app (*WellTang*), whose use for DM2 demonstrated better fasting blood glucose values than for the control subjects.

## Adverse effects of interventions

One important aspect to bear in mind when assessing the efficiency of Apps designed to improve DM self-control is that adverse effects may appear.

Of all the studies included in the seven reviews analyzed herein, a few describe adverse reactions reported by the participants of the intervention groups. Pal *et al.* [14] found a non significant increase in the frequency of mild hypoglycemia episodes in the intervention group, with no differences in severe or nocturnal hypoglycemia episodes [54]. Five studies included in the review by Bonoto *et al.* [41] reported hypoglycemia episodes. One reports averages of 30 and 33 mild episodes in the the intervention and the control group, respectively, and a severe episode in the control group [56]. In three other studies, no significant differences were observed between groups [55,60,61]. In a fifth study, the relative risk of severe hypoglycemia episodes was lower in IG (0:14; 95%CI: 0.07-0.029) [54]. One of the studies in the review by Wu *et al.* [49] found no statistically significant differences between the hypoglycemic events of IG and CG [56]. Two mobile apps (*Diabetes Diary* and *Diabetes Interactive Diary*) reviewed by Veazie *et al.* [45] showed improvements in hypoglycemic episodes of DM1.

Regarding adverse psychological effects, such as stress, anxiety or depression, Wu *et al.* [49] described a significant improvement in anxiety and depression symptoms in four studies [52,62-64].

## Discussion

This work aimed to provide a broad view of the research conducted about using mobile Apps that address lifestyles to control and manage DM. As far as we know, this is the first review of systematic reviews (umbrella review) that considers that the effect of Apps on improving the metabolic control of DM patients.

Although many systematic reviews were found by the literature search, very few met sufficient quality criteria to be included in the present work. Given the variability of Apps and outcome measures, a decision was made to not include the data of the original studies in a meta-analysis.

The seven systematic reviews that acted as the basis for our study showed a clear benefit of mobile Apps that deal with lifestyles to improve DM patients' short-term glycemic control. These data need to be interpreted cautiously because other reasons could have intervened in HbA1c lowering, such as the persuasion of Apps to modify lifestyles [49] or health professionals' access via Apps that include remote communication tools [41]. Indeed the results of a recent pragmatic multicenter clinical random controlled trial did not indicate any differences between the IG (intervention group) and the CG for the primary clinical outcome of glycemic control measured by HbA1c, which also occurred in secondary outcomes like quality of life and behaviors stemming from medical healthcare uses [65].

Finding a convincing explanation for this phenomenon might be a complex matter. Our findings coincide with those of other authors who stated that most studies did not take into account the basis of behavioral health theories when developing Apps [66].

The scientific literature about behavioral health models in which Apps participate reveal very little discussion about behavioral health theories or models that provide a basis on which to support intervention [67]. One possible convincing explanation could lie in the theory of controlling interventions based on other theories. This theory postulates that a synergic association exists between receiving information about someone's behavior (via "self-control" or feedback") and obtaining a strategy with which to act on this information ("planning action" or "information as to how and where to perform behavior"). The former provides a sign and/or motivation for the latter.

The review by Pal *et al.* [14] does not provide sufficient evidence with which interventions improve cardiovascular risk factors (blood pressure, lipid profile and body weight) or cognitive, behavioral or emotional outcomes.

Our findings about long-term effects coincide with those published by other authors by identifying only one positive short-term effect on HbA1c. Indeed very few studies have found a positive long-term effect of Apps on HbA1c [68].

In the subgroups analysis, modification of lifestyles would have a stronger effect on DM2 patients than DM1 patients. This could be explained by the DM1 control depending largely on questions about administering insulin and not about amending lifestyles, which are the main cause for DM2 to appear [6]. Wu *et al.* consider that to ensure Apps being very efficient, a specific design is necessary for all DM subtypes [49]. This must also be done extensively for GD.

Using Apps to control DM seems to reinforce the self-control perception by providing DM patients with better health information and education. It can also increase patient security as to how to deal with their disease by mainly reducing their fear of not knowing how to treat possible hypoglycemia episodes [49,58], and to improve their quality of life [41]. Nonetheless, the impact of these Apps on long-term outcomes, such as quality of life, high blood pressure or frequent diabetes complications (neuropathy and retinopathy), remain unclear. More rigorous longer terms studies are still required to carefully consider the potential of the interaction between patients and health professionals/study personnel (Veazie *et al.* [45] and Lunde *et al.* [48]), along with their effects on DM-related mortality [69].

All the studied Apps focused on two lifestyles, which are most important to control DM well: food and physical exercise. This makes sense as both questions are dealt with simultaneously in clinical practice because they are closely related [6]. However, no Apps that addressed other lifestyles with a high prevalence, like smoking habit, were included [70].

Apart from the characteristics that are typical of Apps to deal with food and physical exercise, others were described because they appear to contribute to improve DM patients' glycemic control to a great extent, such as being able to store and feedback data about blood glucose, support to control doses and therapy with medicines being met and, finally, access to communicate with health professionals.

Among all the studied works, very few described the adverse effects of using Apps. It is necessary to bear in mind that despite potential benefits for patients, the Apps used to calculate insulin doses imply the risk of incorrect dose recommendations that range from those that lead to suboptimum disease control to potentially lethal consequences [71].

Indeed until quite recently, the growth and early adoption of technology both tend to lie mainly in healthcare suppliers' hands. Nowadays, the digital era has extended patients' access to technology. Most of the population has access to portable devices, mobile Apps, with better access to electronic medical records and health data over the Internet. The main leading role of technology in health management, and greater user accessibility and autonomy, are changing the patient's position from a passive person receiving health care to someone who also participates in managing his/her health.

## Limitations

Some limitations appear to interpret and extrapolate the findings of this review. The few data that cover a period longer than 12 months is a major limitation if we consider the chronic condition of DM, and many of its complications are manifested after the disease has been longstanding. Further evidence is necessary to contemplate studies that include longer follow-up periods.

Evaluating the quality of the studied basic reviews was done using AMSTAR for its clear validity and reliability, which helps to identify the best quality evidence for each outcome without prejudicing the quality of the original studies that acted as the basis of the studied reviews. Given this scale's subjectivity component, the evaluation was done both step-wise and independently to minimize this risk.

Another important limitation arose when comparing studies as a result of the low clinical homogeneity of the seven included systematic reviews. Differences were observed in the literature search methods, the inclusion and exclusion criteria, the evaluation of the quality of individual studies, the extraction of primary and secondary outcome measures, and the analysis of the results. The meta-analyses included in five reviews analyzed only a few outcome measures.

## Conclusions

The outcomes of this review will support the use of Apps to improve short-term glycemic control in DM patients. All the examined Apps centered on dealing with food and physical exercise. No significant adverse effects were identified for users of Apps.

Apps' beneficial long-term effect on health for diabetic patients was much weaker. Therefore, more in-depth research is necessary as far as the design, features and effectiveness of studied mobile Apps are concerned to encourage healthy lifestyles for DM patients.

## Abbreviations

**SERGAS:** the Galician Health Service

**HRQOL:** health-related quality of life

**ECA:** controlled random clinical trial

**ns:** not specified

**HbA1c:** glycated hemoglobin

**BMI:** body mass index

**SBP:** systolic blood pressure

**DBP:** diastolic blood pressure

**TC:** total cholesterol

**C-LDL:** low-density lipoprotein cholesterol

**C-HDL:** high-density lipoprotein cholesterol

**TG:** triglycerides

**APPs:** mobile applications

**WHO:** World Health Organization

**IDF:** International Diabetes Federation

**DM:** diabetes mellitus

**DM1:** Type 1 diabetes mellitus

**DM2:** Type 2 diabetes mellitus

**GD:** gestational diabetes

**eHealth:** electronic health

**PRISMA:** Preferred Reporting Items for Systematic reviews and Meta-Analyses

**PROSPERO:** International prospective register of systematic reviews

**NDLTD:** Networked Digital Library of Theses and Dissertations

**AMSTAR:** A Measurement Tool to Assess Systematic Reviews-2

**IG:** intervention group

**CG:** control group

## Declarations

### Author contributions

All the authors were involved in drafting the manuscript. All the authors contributed to develop the selection criteria, the bias risk assessment strategy and the data extraction criteria. AAMQ developed the search strategy. ACF provided her experience in technology assessment. FJRC provided his experience in research into DM. All the authors read, provided comments on and approved the final manuscript.

## Conflicts of interest

None declared.

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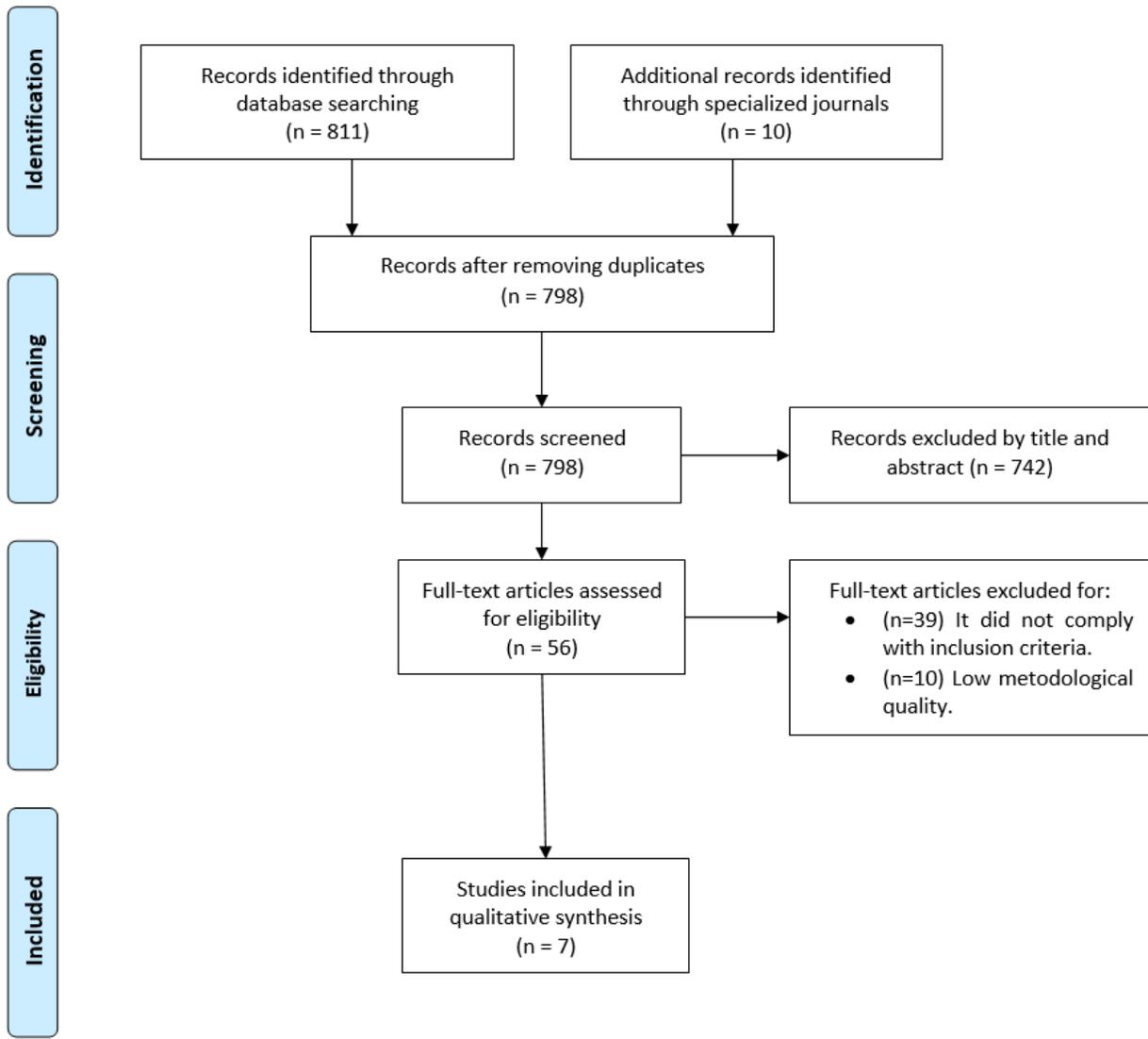
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## Figures



**Figure 1**  
Flow diagram of PRISMA

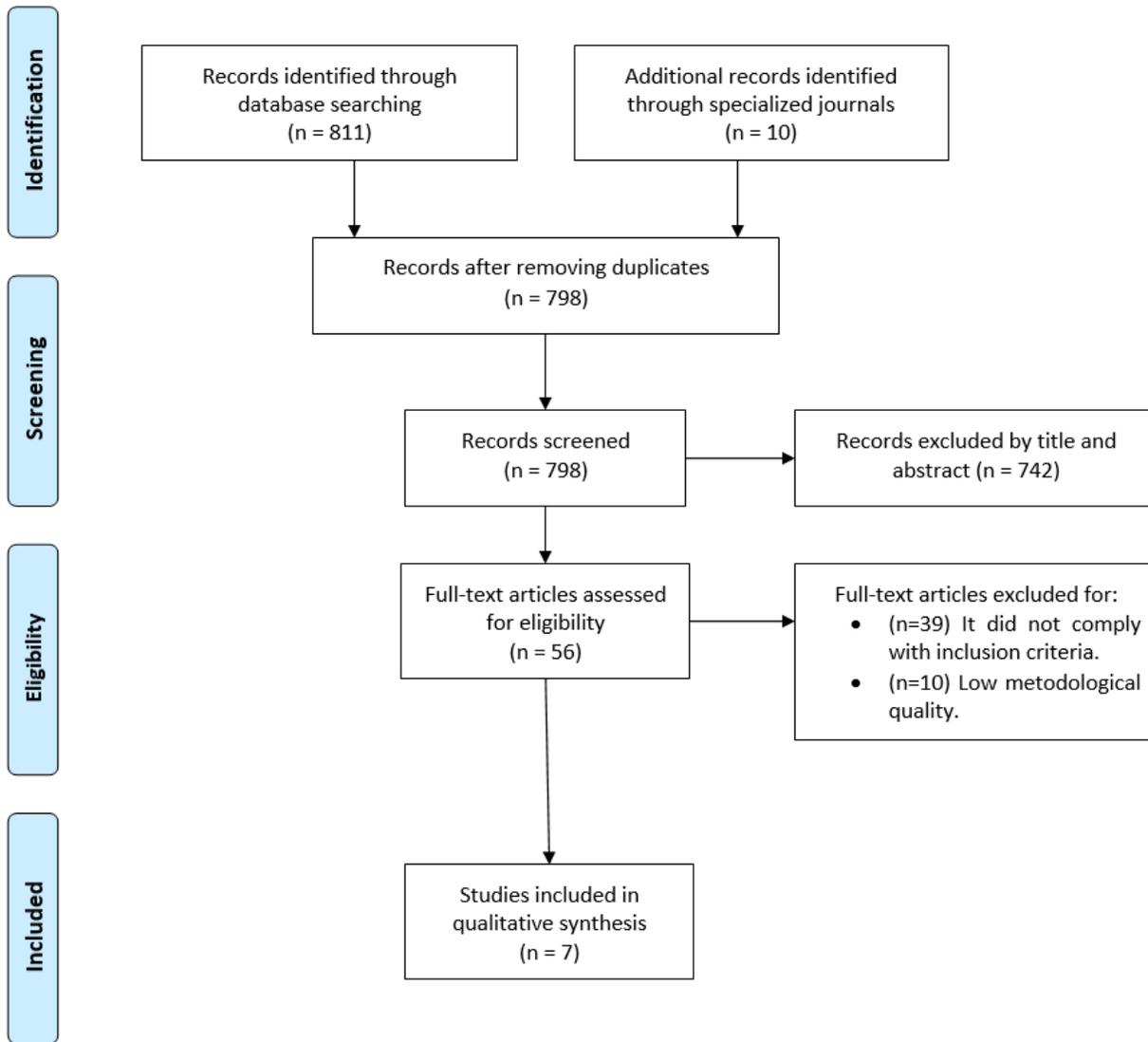


Figure 1

Flow diagram of PRISMA

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