REVIEW

A Systematic Review of Pediatric Telediabetes Service Models

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Abstract

Telediabetes may improve patient access to clinicians who specialize in the management of pediatric diabetes. Due to the diversity of telehealth modes, many different service models for pediatric telediabetes have been developed. This review describes pediatric telediabetes service models identified in the literature, investigates the reported changes in HbA1c of these interventions, and describes enablers and barriers to implementing a telediabetes service. Evaluation of current literature may inform the development and sustainability of telehealth services for pediatric diabetes management. Twenty-nine studies met inclusion criteria and were reviewed. This review has demonstrated that pediatric telediabetes can be delivered by remote monitoring and real-time videoconference modes. Overall, pediatric telediabetes increased interactions between patients and clinicians, improved access to specialized care, and facilitated increased diabetes monitoring. In some contexts, telediabetes also improved short-term glycemic control. Key enablers reported for telediabetes services were integration with existing workflows, dedicated staff, clinician and patient training, appropriate data security, technology with good usability, and the availability of technical support. Barriers included increases in patient responsibilities and clinician workload, and technical issues with equipment and software.

Keywords: Telemedicine, Telehealth, Telediabetes, Pediatric diabetes, Endocrinology.

Introduction

DIABETES CAN BE difficult to manage in the general population, and even more so in pediatric patients.^{1–5} Pediatric patients undergo rapid changes in physical, cognitive, and social development.⁶ These changes increase the complexity of diabetes management. In addition, complicated family structures and family breakdown can lead to inconsistent management.^{7,8} Pediatric patients may have difficulty adhering to treatment plans that require frequent changes as the child grows and matures.^{3,9,10} The need for regular monitoring of blood glucose levels (BGLs) and complex insulin regimens (multiple daily injections and insulin pump therapy) may also be a challenge in this patient group.^{5,11,12}

Children and adolescents often require support from parents, carers, or teachers, before they develop autonomy, and transition to diabetes self-management.^{13,14}

Access to specialized services, regular monitoring, and individualized treatment are needed to achieve optimal diabetic control.^{11,15} There is an increasing need for diabetes services to support and treat pediatric patients to achieve glycemic targets and reduce long-term diabetic complications.^{10,15–17} However, there are limited numbers of clinicians who specialize in pediatric diabetes management, which may make it difficult for patients to receive care.¹⁵ Telehealth may be used to address some of the challenges associated with pediatric diabetes management. Telehealth has been shown to improve access to health care, facilitate

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clinician and patient communication, and improve diabetes monitoring and management.^{5,18,19} Telehealth also encourages a multidisciplinary approach to care as patients can receive services from a variety of health professionals.^{5,20}

Real-time videoconference, store-and-forward (e.g., secure e-mail), and remote monitoring are common modes of telehealth. Remote monitoring (also commonly known as in-home monitoring and telemonitoring) involves the transmission of the patient's biometric data (e.g., BGLs), which is reviewed by a clinician who provides feedback or initiates an intervention to optimize BGLs. Due to the choice of different telehealth modes, a variety of service models for pediatric teledabetes have been developed.

No previous reviews have collated and synthesized available literature describing service models for pediatric teledabetes. Evaluation of this research may inform the development and sustainability of telehealth applications for pediatric diabetes management. Therefore, the aim of this study was to identify and describe pediatric teledabetes service models, investigate reported changes in HbA1c of these interventions, and identify enablers and barriers to service implementation.

Materials and Methods

This review was registered in the International Prospective Register of Systematic Reviews (PROSPERO: CRD42019141239).²¹

Article identification

Peer-reviewed articles published in English between January 2000 and June 2019 were identified using Boolean searches of the PubMed, EMBASE, and CINAHL databases. The search strategy included a combination of MeSH or Emtree terms and keywords related to pediatric teledabetes. The full strategy is available in the published PROSPERO protocol.²¹

Inclusion criteria

Original research articles and study protocols were included if they described the service model for a pediatric teledabetes intervention. Therefore, this review involved a broad range of study types (such as experimental and observational). Articles were included if they described a teledabetes intervention for pediatric patients (or their carers) with diabetes (type 1 or type 2). Articles related to gestational diabetes or diabetic retinopathy were excluded due to their limited applicability to a pediatric population.

Pediatric patients were defined as subjects younger than 18 years when they commenced the intervention. Teledabetes services were defined as digitally enabled clinical services that incorporated interaction between the patient or carer and a clinician. For this reason, articles describing educational interventions or self-monitoring only were excluded. For the purpose of this review, telephone-only services, static websites, or stand-alone text messaging services were not considered teledabetes interventions. All other types of teledabetes technologies (e.g., real-time videoconference, remote monitoring, mHealth, and interactive web-based platforms) were included.

Article selection

Titles and abstracts found using the search strategy were screened independently by two authors (B.S. and M.L.T.). The full texts for these studies were obtained and independently assessed by two members of the research team (K.R.D.G. and M.L.T.) to further assess eligibility. Any study article where eligibility could not be agreed upon by (K.R.D.G. and M.L.T.) was assessed by a third and fourth reviewer (B.S. and C.L.S.).

Data extraction and reporting

Data were extracted from the full text articles. The following fields were included in the data extraction: country, study type, participant type, service model description (including the mode and type of technology), HbA1c results, and key findings. Each study type was also assigned a level of evidence, according to the National Health and Medical Research Council (NHMRC) hierarchy of evidence.²² Where required, authors were contacted to find information regarding the service model that was not described in the article. Synthesis of findings was narrative in keeping with the study aim of describing different service models. Findings were reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.²³

Quality assessment

The Standards for Quality Improvement Reporting Excellence (SQUIRE) 2.0 checklist was used to assess the reporting quality of each article.²⁴ Each article was assigned a score out of 18 points. Higher scores indicated a higher reporting quality. SQUIRE content items included analysis of title, abstract, introduction, methods, results, discussion, conclusion, and other information.²⁴ SQUIRE enabled a comparison of reporting quality across different study types identified in the included articles. Protocol articles were assigned a total possible score out of nine, as not all items were relevant to them.

Results

Study selection

In total, the literature search resulted in the selection of 29 studies that met the inclusion criteria.^{1-4,7,9,11,12,14-17,20,25-40} The search and screening process is shown in the PRISMA flow diagram (Supplementary Fig. S1).

Study characteristics

All studies described pediatric teledabetes service models (Table 1). Articles were published between 2000 and 2019. Studies were conducted in 13 different countries, with the majority of services from the United States ($n=15$, 52%).^{1,4,7,17,26-30,33-36,39,40} The most common study type was a randomized controlled trial (RCT) ($n=11$, 38%).^{3,7,11,16,17,20,25,28,30,31,37} Most studies were conducted over 24 weeks ($n=9$, 31%),^{1,4,15-17,20,26,27,31} with the minimum study length at 12 weeks,^{3,12,26} and the maximum study length at 240 weeks.³⁷ There were two protocols included in this review.^{35,36}

TABLE 1. STUDY CHARACTERISTICS AND PEDIATRIC TELEDIABETES SERVICE MODEL DESCRIPTION

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min–max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Berndt et al., ¹¹ 2014 (Germany)	Remote monitoring/ Smartphone application (Android/iOS) “Mobile diab” and web-based portal	RCT, II	68 telediabetes = 34	13 (8–18)	Type 1	4	Blood glucose levels, nutrition, and drug information were entered into <i>Mobilediab</i> . Clinicians accessed these data and gave feedback through a web-based portal. Out-of-range BGLs were detected.	15
Boogerd et al., ²⁰ 2017 (Netherlands)	Remote monitoring/ web-based portal “Sugarsquare”	RCT, II	105 telediabetes = 54	9 (0–13)	Type 1	24	Parents contacted the diabetes team by <i>Sugarsquare</i> . Parents communicated with clinicians using a chat or forum application.	18
Cadario et al., ²⁵ 2007 (Italy)	Remote monitoring/ web-based tool or mobile tool “Glucosebee” connected to glucometer	RCT, II	28 telediabetes = 14	15 (10–20)	Type 1	96	Glucometer data were transferred through <i>Glucosebee</i> to a clinician’s computer every 2 weeks. Clinicians gave feedback in a 1-min vocal message to the patient’s cell phone within 1–2 days (no later than 1 week).	9
Carroll et al., ¹ 2011 (United States)	Remote monitoring/ integrated cell phone and glucose meter “Glucosephone”	Noncontrolled nonrandomized trial, IV	40	Not reported (13–18)	Type 1	24	<i>Glucosephone</i> transmitted self- monitored BGLs to a clinician’s computer. An algorithm identified out-of- range BGLs. The clinician reviewed daily and gave feedback (e.g., dose adjustments) through text message or telephone.	17
Choi et al., ²⁶ 2013 (United States)	Remote monitoring/ web-based and e-mail communication	Retrospective uncontrolled cohort study, IV	31	12 (7–18)	Type 1	24	BGLs, CGM, and insulin doses were transmitted from insulin pumps to a website, which was viewable by clinic staff. Insulin dose adjustments were given by web-based and e-mail communication to patients.	12

(continued)

TABLE 1. (CONTINUED)

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min–max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Crossen et al., ²⁷ 2019 (United States)	Real-time videoconference/ Vidyo Desktop and internet platform	Uncontrolled nonrandomized trial, IV	57	Not reported (1–17)	Type 1	24	Glucometer data, insulin pump, and/or CGM data were uploaded to a platform for the videoconference consultation. Consultations were conducted by an endocrinologist.	15
D'Annunzio et al., ² 2003 (Italy)	Remote monitoring/ web-based communication supported by hospital intranet server	Uncontrolled nonrandomized trial, IV	6	Not reported (10–16)	Type 1	59	BGLs and insulin dosages were sent from the PU to the MU, a web-based workstation in the hospital. The clinician viewed the data and messages were exchanged between the PU and MU.	13
Doger et al., ¹⁵ 2019 (Turkey)	Real-time videoconference/ smartphone application “WhatsApp” and SMS	Uncontrolled nonrandomized trial, IV	82	11 (2–18)	Type 1	24	Clinicians gave counseling at scheduled times (11:30– 14:30 and 21:00–24:00). Messages were sent through WhatsApp and SMS. WhatsApp enabled voicemails and audio and video calls.	15
Duke et al., ²⁸ 2016 (United States)	Real-time videoconference/ free internet- teleconferencing platform	RCT, II	90 telediabetes = 46	15 (12–19)	Type 1	12	BFST-D were delivered by clinicians by real-time videoconference to patients at home.	18
Freeman et al., ⁷ 2013 (United States)	Real-time videoconference/ Skype	RCT, II	71 telediabetes = 32	15 (12–19)	Type 1	12	BFST-D was delivered by clinicians through Skype. Participants received up to 10 BFST-D sessions lasting for 1–1.5 h over 12 weeks.	18
Froisland and Arsand, ⁹ 2015 (Norway)	Remote monitoring/ smart-phone and mobile-phone- based diabetes diary “Diamob”	Uncontrolled nonrandomized trial, IV	12	Not reported (13–19)	Type 1	12	Insulin doses, BGLs, CGM data, and pictures of meals were entered into or automatically transferred to Diamob, which was viewable on a clinician's computer. Patients communicated with clinicians through SMS.	14

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TABLE 1. (CONTINUED)

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min–max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Gandrud et al., ¹⁷ 2018 (United States)	Remote monitoring/ smart-phone (iPhone or android) and “Diasend” web- based platform	RCT, II	117 telediabetes = 60	13 (8–17)	Type 1	24	Insulin pump data, glucose sensor information, and Fitbit step count data were uploaded to the clinic using smartphones or <i>Diasend</i> . Clinicians viewed this weekly. Feedback was given to parents by e-mail or telephone.	17
Guttmann-Bauman et al., ²⁹ 2018 (United States)	Real-time videoconference	Questionnaire, IV	27	Not reported (5–18)	Type 1	Not applicable	Endocrinologists conducted consultations through videoconference. Medical assistants performed point- of-care HbA1c testing and downloaded glucometer and insulin pump data, which could be reviewed by the specialist during the consultation.	11
Izquierdo et al., ³⁰ 2009 (United States)	Real-time videoconference and remote monitoring/ (V-Connect), web-based portal and BGL interpretation software (Lifescan)	RCT, II	41 telediabetes = 23	10 (5–14)	Type 1	52	An application portal allowed exchange of graphical and tabular glucose measurement information between the school nurse and diabetes team. Videoconference visits (10–20 min) were conducted monthly with the school nurse, diabetes team, and patient.	15
Klee et al., ³ 2018 (Switzerland)	Remote monitoring/ smartphone mHealth application “Webdia” and web-based portal	RCT, II	55 telediabetes = 28	14 (10–18)	Type 1	12	BGLs and meal pictures were entered into the app, which could be viewed by a clinician through a web- based portal. Feedback was given through monthly e-mails to patients.	17

(continued)

TABLE 1. (CONTINUED)

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min-max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Landau et al., ³¹ 2012 (Israel)	Remote monitoring/ web-based “Medtronic” Internet site	RCT, II	70	15 (11–20)	Type 1	24	Self-monitored BGLs were uploaded to <i>Medtronic</i> . The patient e-mailed a study coordinator to inform them of the upload. The study coordinator viewed data in <i>Medtronic</i> , consulted a specialist, and called the patient to give feedback.	15
Liesenfeld et al., ³² 2000 (Germany)	Remote monitoring/ glucometer (Accutrend DM, Roche), Palmtop computer (Apple Newton) and PC	Uncontrolled nonrandomized trial, IV	54	15 (5–18)	Type 1	19	Glucometer data were transferred from the device to a palmtop computer, and then to the PC at the diabetes center. Clinicians could view the data and gave feedback through a telephone call.	11
Lowe et al., ¹⁴ 2005 (United Kingdom)	Remote monitoring/ website	Questionnaire, IV	72	13 (11–16)	Type 1 and type 2	Not applicable	A patient website that would include 24-h access to records and information, anonymous access to advice “ask an expert,” and a chat room for peer support.	11
Malasanos et al., ³³ 2005 (United States)	Real-time videoconference	Retrospective review of service activity ^b	Not applicable	Not reported	Type 1 and type 2	Not applicable	FITE diabetes project provided semimonthly telemedicine clinics. Nurses performed clinical evaluations of patients by videoconference with a specialist.	15
Malasanos et al., ³⁴ 2005 (United States)	Remote monitoring/ glucose meters (OneTouch, LifeScan, Inc., Milpitas, CA) and secure e-mail	Retrospective review of service activity ^b	Not applicable	Not reported	Type 1 and type 2	Not applicable	Glucometer data were transmitted weekly to the patient’s computer, and then the communication interface, to the FITE team, and CMS nurses. Communication between school nurses, CMS nurses, and FITE team occurred through secured e-mail accounts.	9

(continued)

TABLE 1. (CONTINUED)

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min-max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Nigrin and Kohane, ³⁵ 2000 (United States)	Remote monitoring/ computer application “GlucoWeb”	Protocol ^b	Not applicable	Not Applicable	Not Applicable	Not applicable	Patients transmit glucometer data to their computer, which can be retrieved by a clinician through a secure database. Patients can e-mail BGLs, with attached text messages, to clinicians. <i>GlucoWeb</i> allows analysis of BGLs with graphical and tabular formats. An algorithm can detect out-of- range BGLs.	8 (out of 9)
Pena et al., ¹² 2013 (Spain)	Remote monitoring/ Accu-Chek Smart Pix Software and web-based platform (Emminens conecta system)	Prospective noncontrolled cohort Study, IV	13	8 (6–10)	Type 1	12	Families sent self-monitored BGLs, insulin doses, and hypo glycaemic or hyperglycaemic episodes to clinicians through the web. Data were analyzed using graphs generated by the software. Clinicians gave feedback through the web, or SMS service, within 24 h of received data.	17
Pinsker et al., ⁴ 2011 (United States)	Remote monitoring/ website (PDEP)	Uncontrolled nonrandomized trial, IV	52	11 (Not reported)	Type 1	24	HbA1c testing and summary graphs for CGM were posted to PDEP. Each patient had a case file on PDEP, viewable by clinicians. Families posted questions to clinicians through the website.	15
Rami et al., ¹⁶ 2006 (Austria)	Remote monitoring/ cell-phone (Nokia 3510) and “VIE- DIAB” program	Crossover RCT, II	36	Not reported (11–19)	Type 1	24	Self-monitored BGLs, insulin doses, and carbohydrate intake was sent through mobile server viewable by clinicians. <i>VIE-DIAB</i> collected and processed these data. Clinician feedback was sent through an SMS once a week.	15

(continued)

TABLE 1. (CONTINUED)

<i>Author, publication year (country)</i>	<i>Mode/technology</i>	<i>Study type, NHMRC level of evidence^a</i>	<i>n</i>	<i>Mean age-years (min–max)</i>	<i>Diabetes type</i>	<i>Study length (weeks)</i>	<i>Service model description</i>	<i>SQUIRE score (18-items)</i>
Recupero et al., ³⁶ 2013 (United States)	Remote monitoring/ MedApps HealthPAL device connected to a glucometer	Protocol ^b	Not applicable	Not applicable	Not applicable	Not applicable	MedApps HealthPAL device collected glucometer readings and transmitted them to PDEP website. After posting weekly readings, clinicians were notified by e-mail. Clinicians can log into PDEP and send feedback.	8 (out of 9)
Schiaffini et al., ³⁷ 2016 (Italy)	Remote monitoring/ web-based system (Diasend system or Interactive Medtronic platform)	RCT, II	29 type 1 diabetes = 15	13 (Not reported)	Type 1	240	Glucose and pump parameters were downloaded on a personal profile of the online website. Clinician feedback was provided during virtual sessions at 1-month intervals. Parents also had access to the website.	15
Smith et al., ³⁸ 2003 (Australia)	Real-time videoconference/ document camera	Retrospective review of service activity ^b	Not applicable	Not reported	Type 1 and type 2	Not applicable	Patient consultations were conducted through videoconference. A document camera was used for the transmission of data (blood sugar records and growth percentile charts).	15
Smith and Satyshur, ³⁹ 2016 (United States)	Real-time videoconference	Survey, IV	14	Not reported (2–18)	Type 1 and type 2	Not applicable	Videoconference consultations were conducted by APRNs. APRNs reviewed uploaded data (HbA1c and BGLs) through a 2-way videoconference with the specialist.	16
Wood et al., ⁴⁰ 2016 (United States)	Real-time videoconference/ Cisco Jabber	Uncontrolled nonrandomized trial, IV	54	12 (2–18)	Type 1	52	Videoconference consultations were conducted monthly at local diabetes centers with clinician at the BDC. BGL data and insulin pump data were sent to the BDC by fax or e-mail, to be viewed by clinicians.	17

^aNHMR level of evidence of II is an RCT, III-1 is a pseudo-RCT, III-2 is a comparative study with concurrent controls, III-3 is a comparative study without concurrent controls, and IV is a case series with either post-test or pre-test/post-test outcomes.

^bThe NHMRC level of evidence was not applicable to protocols or retrospective reviews of service activities.
APRN, advanced practice registered nurse; BDC, Barbara Davies Center; BFST-D, behavioral family systems therapy-diabetes; BGL, blood glucose level; CGM, continuous glucose monitoring; CMS, Children's Medical Centre; FITE, Florida Initiative in Telehealth and Education; MU, medical unit; NHMRC, National Health and Medical Research Council; PC, personal computer; PDEP, Pediatric Diabetes Education Portal; PU, patient unit; RCT, randomized controlled trial; SQUIRE, Standards for Quality Improvement Reporting Excellence.

Service models

The majority of included studies used remote monitoring ($n=19$, 66%) as the main mode for delivering pediatric teledabetes services.^{1-4,9,11,12,14,16,17,20,25,26,31,32,34-37} Other modes included real-time videoconference ($n=9$, 31%),^{7,15,27-29,33,38-40} or a combination of remote monitoring and real-time videoconference modes ($n=1$, 3%).³⁰ Store-and-forward was not used by any of the included studies. The service models utilized ancillary technologies, including mobile applications and web-based platforms. Some remote monitoring services had algorithms to alert out-of-range BGLs, which facilitated clinical review of the patient.^{1,11,35} Direct engagement between local clinicians and specialists during real-time videoconference sessions also led to training and educational opportunities.^{33,38,39}

Study reporting quality

The median SQUIRE score for all included articles was 14, demonstrating an overall high quality of reporting. Three articles (10%) were allocated a complete score of 18.^{7,20,28} The main reasons for reductions in score were failure to adequately report certain items such as the rationale, reliability, and validity of measures ($n=14$, 48%)^{2,14-16,25-27,29,33-38}; study limitations ($n=13$, 45%)^{2,4,9,11,14,25,32-38}; and the context for the intervention ($n=12$, 41%).^{2,4,12,16,17,25,27,31,32,35-37}

Clinical effectiveness

Seventeen studies examined HbA1c (Table 2), and some of these studies also reported additional outcome measures.^{2-4,11,12,15-17,25-27,29-32,37,40} The remaining studies did not report HbA1c and focused on satisfaction, feasibility, psychosocial effectiveness, usability, or a combination of these (Table 2). The results for change in HbA1c varied, making it difficult to determine the clinical effectiveness of pediatric teledabetes. Out of the 17 studies that examined HbA1c, 9 studies (53%) were RCTs.^{3,4,11,16,17,25,30,31,37} The other eight studies (47%) examined pediatric teledabetes without a control group.^{2,12,15,26,27,29,32,40} Seven of the nine RCTs (78%) reported improvements in HbA1c in the teledabetes group compared to the control group.^{3,4,16,17,25,30,37} The remaining two RCTs (22%) reported no significant differences between groups.^{11,31}

Out of the eight studies without a control group, five studies (63%)^{12,15,26,27,32} reported HbA1c improvements and three studies (38%)^{2,29,40} reported no significant change in HbA1c. None of the included studies reported worsening of HbA1c as a result of the teledabetes intervention. D'Annunzio et al.,² Izquierdo et al.,³⁰ and Pena et al.¹² did not report HbA1c values so the clinical effect of the teledabetes intervention could not be determined. The majority of studies measured HbA1c after participants had received the teledabetes intervention for 6 months. Although there were mixed HbA1c results, pediatric teledabetes was found to be feasible,^{16,20,27,30} and most patients, families, and carers expressed satisfaction with these service models.^{1,4,14,17,27,29,39,40}

Enablers and barriers

Enablers and barriers associated with the delivery of pediatric teledabetes services were identified across service models (Table 3). Enablers were patient and clinician

training^{7,12,25,29-31,33,34,37-39}; secure technology and subsequent data confidentiality^{11,20,34}; increased usability and convenience of the technology; and delegation of a team member to coordinate the teledabetes service.²⁰ The most common barriers included technical difficulties,^{1,2,4,15,30,40} concern over data security,³⁴ lack of reimbursement for telehealth activities,^{29,30,40} and the potential for increased patient responsibilities and clinician workload.^{1,2,16}

Discussion

This review identified and described 29 pediatric teledabetes service models along with enablers and barriers to implementing these services. Remote monitoring (66%) and real-time videoconference (31%) were the most common mode of delivering pediatric teledabetes services. HbA1c was investigated by 17 of the included studies. Overall, the findings were mixed, with 78% of randomized controlled studies and 63% of noncontrolled studies reporting improved glycemic control for teledabetes. For the remaining studies, there was no significant change between teledabetes and standard care (in-person consultations). No study reported worsening of HbA1c.

Differences in patient's age, sociodemographic characteristics, baseline HbA1c, diabetes type, stage of disease, insulin regimen, and BGL monitoring may explain variability in reported findings. For example, enrolment eligibility was different for each study with duration of diabetes required to be over 6 months for Landau et al.³¹; over 1 year for Rami et al.¹⁶ and Klee et al.³; and over 2 years for Cadario et al.²⁵ Many of the included studies were examined with the short-term benefits, which raises the question as to whether the finding of HbA1c improvement truly reflects long-term benefit.

In short-term follow-ups, patients may modify their behavior due to their awareness that they are being monitored. For instance, Gandrud et al.¹⁷ found HbA1c improvement was not sustained when measured 3 months postintervention, while Pena et al.¹² reported worsening of glycemic control after cessation of the teledabetes intervention. Conversely, Schiaffini et al.³⁷ followed patients for 5 years; however, they only included sensor-augmented pump-treated adolescents, and their results may not be applicable to patients using different insulin regimens (e.g., multiple daily injections) with self-monitored BGLs.

This review demonstrated that pediatric teledabetes increased interactions between patients and clinicians, resulting in improved access to specialized care and efficient diabetes monitoring. Increased clinician interaction and additional support for diabetes management are particularly important for pediatric patients.^{13,14} A multidisciplinary approach was encouraged by some services.^{20,30,34,39,40} This was a positive outcome because pediatric patients were able to access a variety of health professionals and clinical services. Other service models created a supportive network of care by involving diabetes teams, clinicians, school nurses, and caregivers.^{30,34}

Successful service models were found to be integrated with existing health care systems. Boogerd et al.²⁰ highlighted that a designated telehealth team member helped integrate their service into practice. Shared workload, established partnerships, and a common goal were identified as key enablers of

TABLE 2. STUDY OUTCOMES (PROTOCOL STUDIES EXCLUDED)

Author, publication year	Article focus	Key findings	Reported results for HbA1c
Cadario et al., ²⁵ 2007	Clinical effectiveness	HbA1c decreased in the telediabetes group compared to the control group. As a result, the control group was introduced to telediabetes at 6 months.	HbA1c at baseline, 3 months and 6 months was 9.5, 9.0, and 9.1 for the telediabetes group and 9.1, 9.4, and 9.4 for the control group.
Choi et al., ²⁶ 2013	Clinical effectiveness	A further improvement in HbA1c was reported after 18 months ($P=0.01$). HbA1c levels were significantly lower at 3 and 6.5 months compared to baseline. There were no differences in HbA1c for age comparisons, insulin delivery methods, or number of telediabetes encounters.	HbA1c from baseline to 3 months was 11.1 vs. 9.1 ($P<0.05$), and from baseline to 6.5 months, was 11.1 vs. 9.5 ($P<0.05$).
D'Annunzio, et al., ² 2003	Clinical effectiveness	There was no significant change in HbA1c. There was a positive correlation between number of insulin protocol changes, and HbA1c decrease was found ($P=0.02$).	No actual HbA1c values were reported, only correlations.
Doger et al., ¹⁵ 2019	Clinical effectiveness	Increase in counseling through telediabetes from clinicians resulted in improved metabolic control. There was a preference for <i>Whatsapp</i> communication. HbA1c was significantly lower in patients frequently calling ($P<0.001$).	HbA1c for frequent callers (telediabetes) was 8.30 ± 1.16 at baseline and 7.45 ± 0.87 at 6 months.
Gandrud et al., ¹⁷ 2018	Clinical effectiveness	Telediabetes improved quality of life among pediatric diabetic patients. Telediabetes improved HbA1c at 6 months ($P=0.071$); however, this was not sustained after the telediabetes intervention was ceased, which was assessed 3 months postintervention.	The mean HbA1c (SD) change was -0.34 (0.85) and -0.05 (0.74) for telediabetes and control groups at 6-month follow-up.
Liesenfeld et al., ³² 2000	Clinical effectiveness	Telediabetes can improve metabolic control in pediatric patients with diabetes, while reducing the number of hypoglycemics ($P=0.01$).	Mean HbA1c reduction was 0.4 (-3.8 to 2.2, $P=0.05$) at the end of the 19-week telediabetes program.
Schiaffini et al., ³⁷ 2016	Clinical effectiveness	Telediabetes resulted in patients being more compliant with their diabetes self-management. Glycemic control improved; HbA1c values were significantly lower in the telediabetes group compared to control group.	Mean HbA1c was 7.5 ± 0.3 in the telediabetes group compared to 7.8 ± 0.2 in control ($P=0.03$) at the whole follow-up period (5 years).
Berndt et al., ¹¹ 2014	Clinical effectiveness and satisfaction	There were no significant differences between the telediabetes and control groups for change in HbA1c ($P=0.65$). There was good acceptance of the system.	Mean (SD) reduction for the control group and telediabetes group was 0.98 (1.45) and 0.72 (1.48) respectively.
Guttmann-Bauman et al., ²⁹ 2018	Clinical effectiveness and satisfaction	The number of yearly visits to the clinic increased from 1.5 to 2.7 ($P<0.0001$). Patients expressed high satisfaction: 89% found telediabetes equivalent to in-person visits. There was no significant change in HbA1c.	HbA1c was 8.7 (95% CI: 8.1–9.4) pretelediabetes and 8.8 (95% CI: 8.2–9.3) in the first year of telediabetes.
Klee et al., ³ 2018	Clinical effectiveness and satisfaction	Telediabetes was well accepted by users; 46.4% rated the service as good and 39.3% as excellent. Telediabetes resulted in a significant decrease in HbA1c compared to controls ($P=0.048$) in patients with HbA1c $>8\%$.	Patients HbA1c $>8\%$: reduction of 0.33% in the telediabetes group compared with increase of 0.21% in control group at 3-month follow-up.
Landau et al., ³¹ 2012	Clinical effectiveness and satisfaction	Telediabetes was not associated with improved glycemic control and there were no significant differences in HbA1c in the telediabetes and control groups. Most patients found telediabetes useful for diabetes management.	Mean HbA1c was 8.5 ± 1.4 for the telediabetes group and 8.4 ± 1.1 for the control group ($P=0.54$) at 6-months follow-up.
Pena et al., ¹² 2013	Clinical effectiveness and satisfaction	Telediabetes was well accepted by patients and parents. It improved metabolic control by reducing HbA1c values and glycemic variability. However, after cessation of telediabetes, metabolic control worsened.	No actual HbA1c values were reported. Mean HbA1c levels were significantly reduced with telediabetes at 3 months ($P=0.012$)
Pinsker et al., ⁴ 2011	Clinical effectiveness and satisfaction	Website users reported satisfaction with the intervention and felt that it improved diabetes self-management. There was a significant improvement in HbA1c between telediabetes users and nonusers ($P=0.03$)	Mean HbA1c from baseline to 6 months was 10.5 ± 2.2 to 9.1 ± 1.2 for telediabetes users and 9.5 ± 1.5 to 10.4 ± 2.5 for nonusers.
Wood et al., ⁴⁰ 2016	Clinical effectiveness and satisfaction	Telediabetes was equivalent to in-person visits; there was no significant difference in HbA1c at baseline and at 1 year. Patients and families missed significantly less school and work with telediabetes ($P<0.0001$). Patients reported high satisfaction with the program.	Mean HbA1c was 9.3 ± 1.5 at baseline and 9.8 ± 1.7 after 1 year of telediabetes ($P=0.07$).

(continued)

TABLE 2. (CONTINUED)

<i>Author, publication year</i>	<i>Article focus</i>	<i>Key findings</i>	<i>Reported results for HbA1c</i>
Crossen et al., ²⁷ 2019	Clinical effectiveness, and satisfaction, and feasibility	Telediabetes was feasible and satisfactory for patients and resulted in significant improvement in HbA1c. Around 94% of patients were “very satisfied with the system.”	Mean HbA1c reduction was 0.8 (95% CI: 0.2–1.4; $P=0.007$) at 6-month follow-up.
Izquierdo et al., ³⁰ 2009	Clinical effectiveness and feasibility	Telediabetes through school programs can improve diabetes care for pediatric patients. There was significant improvement in several subscales of pediatric quality-of-life results.	No actual HbA1c values were reported. HbA1c decreased in the telediabetes cohort ($P>0.02$) at 6 months.
Rami et al., ¹⁶ 2006	Clinical effectiveness and feasibility	Overall satisfaction with telediabetes intervention was good and proved feasible. Glycemic control improved with TM support and deteriorated with conventional support (PD) phase.	This study employed a crossover RCT. The median HbA1c for the TM-PD group was 9.05 (0 months), 8.9 (3 months), and 9.2 (6 months), and PD-TM group was 8.9 (0 months), 9.9 (3 months), and 8.8 (6 months) ($P<0.05$). Not reported
Froisland and Arsand, ⁹ 2015	Clinical effectiveness and usability	A visualization tool can assist pediatric patients in understanding their diabetes. Mobile applications were useful for diabetes self-management, supported by system usability scale scores. HbA1c improved in seven patients.	Not reported
Smith and Satychur, ³⁹ 2016	Satisfaction	Caregivers were satisfied with telediabetes as an alternative to in-person visits. Advanced practice nurses can help implement telediabetes services to improve access to care.	Not reported
Carroll et al., ¹ 2011	Satisfaction and feasibility	Adolescents reported positive feelings toward telediabetes and the service. Telediabetes did not change quality of life, level of conflict with parents, or self-management of diabetes.	Not reported
Boogerd et al., ²⁰ 2017	Feasibility	The trial was considered feasible. There was moderate acceptability and demand in parents and high acceptability and demand in clinicians. There were no significant differences in parenting stress ($P=0.49$).	Not reported
Lowe et al., ¹⁴ 2005	Feasibility	Around 95% of respondents reported a positive attitude to the potential telediabetes clinic. The ability to “ask an expert” was rated as the most useful feature.	Not reported
Duke et al., ²⁸ 2016	Psychosocial effectiveness	BFST-D delivered through telediabetes yields outcomes no different from clinic-based treatment. Scores for miscarried helping, family conflict, and adjustment to illness were not significantly different between groups.	Not reported
Freeman et al., ⁷ 2013	Psychosocial effectiveness	BFST-D delivered through real-time videoconference does not impact therapeutic relationships. There was no difference in the scores of working alliance inventory between groups.	Not reported
Malasanos et al., ³³ 2005	Retrospective review of service activity	The mean interval between visits decreased in year 1 and 2 of the telediabetes program. Over 90% of patients expressed satisfaction with the service. The program saved US\$27,860 per year.	Not reported
Malasanos et al., ³⁴ 2005	Retrospective review of service activity	Patients, families, and nurses expressed satisfaction with the technology. Around 44 patients, 6 caregivers, 6 case managers, and 18 nurses were involved. Over 90% of patients or nurses received equipment for glucometer transmission.	Not reported
Smith et al., ³⁸ 2003	Retrospective review of service activity	Around 160 consultations and 10 education sessions were facilitated by the service in the first 28 months. The median time for routine clinics was 130 min. The telediabetes service improved access to specialist services from rural and remote areas.	Not reported

CI, confidence interval; PD, paper diary; SD, standard deviation; TM, telemedical.

TABLE 3. REPORTED ENABLERS AND BARRIERS FOR PEDIATRIC TELEDIABETES SERVICE MODELS

<i>Author, publication year</i>	<i>Enablers</i>	<i>Barriers</i>
Berndt et al., ¹¹ 2014	Implementation ensured security and confidentiality of patient information (authentication methods and different authorization levels)	None reported
Boogerd et al., ²⁰ 2017	Designated nurse practitioner who moderated web-based portal Appointed team member dedicated to the telediabesity service Implementation ensured security of patient information (two-factor authentications) Telediabesity training for patients and clinicians	Absence of instructions for when and how to use telediabesity Difficulty in integrating telediabesity into clinician's workflow due to the research context of the intervention None reported
Cadario et al., ²⁵ 2007	Telediabesity orientation to patients and clinicians System instruction manuals for nurses Nurses were able to contact study personnel	Gaps in service and technology shortfalls Rural areas lacked uniform cell phone service (service interruptions) Technical issues (some mobiles sent back to vendor) Increased workload for clinicians None reported
Carroll et al., ¹ 2011	None reported	Technical issues with technology (e.g., loss of internet access)
Choi et al., ²⁶ 2013	Multipoint real-time videoconference consultations were convenient for families or carers (did not miss school or work appointments)	Increased workload for clinicians
Crossen et al., ²⁷ 2019	Responsiveness increased: telediabesity enabled prompt insulin dose changes Technical personnel were available to users or clinicians at any time	Feasibility was affected as the service location was in the hospital Technical personnel were needed to support users at home
D'Annunzio et al., ² 2003	Exchange of information through preferred communication pathway was possible (audio, image, speech, and video) Telediabesity training for families Written instruction for families on how to download the video software Technical assistance provided when families had system issues Preparatory telediabesity training for clinicians and weekly supervision	Telediabesity service did not belong to their institution and was not accessible 24 h a day Technology developed for business and personal applications and had not been approved for health applications
Doger et al., ¹⁵ 2019	Visual understanding of how insulin doses and food intake interact, through telediabesity exchange of pictures of food eaten ^a	Not reported
Duke et al., ²⁸ 2016	Reminders from the research staff for patients to upload data ^a	Not reported
Freeman et al., ⁷ 2013	Telediabesity coordinator trained local medical assistants on maintaining equipment, downloading data, and performing point-of-care HbA1c tests ^a Telehealth service reimbursement is mandated for all insurers in Oregon	Licensing requirements, privacy concerns, and uneven reimbursement climate in the United States
Froisland and Arsand., ⁹ 2015	Implementation involved initial one-on-one in-person tutorial session (1.5 h) from the project IT coordination to train nurses on telediabesity ^a Service assistance available by call to a toll-free help desk ^a	Initial technical difficulties due to connectivity (school firewalls) Intervention run at an inconvenient time (necessitating a 6-month break for summer vacation with no intervention)
Gandrud et al., ¹⁷ 2018	Simultaneous review of data with real-time videoconference A 45-min tutorial from two specialized nurses on installation of the technology onto mobile devices, introduction to app functions, and creation of a user account	Insurance carriers do not reimburse telediabesity activities BGIs were entered into the system manually Application designed for a 10-year-old girl (may not appeal to an older age group) Not reported
Guttmann- Bauman et al., ²⁹ 2018	Training provided to patients to upload glucose meter data to website ^a	
Izquierdo et al., ³⁰ 2009		
Klee et al., ³ 2018		
Landau et al., ³¹ 2012		

(continued)

TABLE 3. (CONTINUED)

<i>Author, publication year</i>	<i>Enablers</i>	<i>Barriers</i>
Liesenfeld et al., ³² 2000	Implementation considered affordability; there were no costs associated for the patient and no home personal computer expertise was required ^a	Not reported
Lowe et al., ¹⁴ 2005	Not reported	Not reported
Malasanos et al., ³³ 2005	Training provided to nurses on how to use real-time videoconference and hand camera equipment ^a	Not reported
Malasanos et al., ³⁴ 2005	Implementation focused on technology training for students and nurses Implementation ensured security of information (met U.S. federal privacy standards for the transmission of health care data) Technical questions were automatically sent to the helpdesk ^a Program graphics intended to appeal to pediatric age group Implementation ensured security of information (several authentication and security mechanisms) ^a	Reluctance from clinicians in sending health information by e-mail due to privacy concerns ^a
Nigrin and Kohane, ³⁵ 2000	First phase of implementation involved the provision of training sessions for how to use telediabetes technology ^a	Not reported
Pena et al., ¹² 2013	The system had an in-built billing system ^a Increased usability as clinicians could switch between patient cases on the website and could forward cases to other physicians for review Not reported	No legal support in Spain for telediabetes activities Barrier to participation included refusal to engage with telediabetes due to the number of daily glucose readings required Less convenient as data had to be manually uploaded (no automatic transmission of information) Technical issues with login and posting comments Patients had to manually send data and there was access to data issues
Pinsker et al., ⁴ 2011	Increased convenience through automatic transfer and upload of BGLs	Not reported
Rami et al., ¹⁶ 2006	Initial telediabetes training for patients and repeated at 24-month intervals Future use could include a "Triage app" to enable quick feedback for patients and a priority list for clinicians Educational and training opportunities for less experienced medical staff who participated in consultations with specialists Discussion with multisite audiences was possible	Not reported
Recupero et al., ³⁶ 2013	Established partnership between the tertiary center and remote rural site Leadership team provided management and support in terms of financial resources and telediabetes training Real-time videoconference outreach visits at local diabetes center enabled complete set of patient data to be available at the time of consultation ^a	Nurses and primary care providers expressed the need for more education on telemedicine Limited space and support staff for the demand of referrals Technical difficulties with technology Real-time videoconference in-home visits were not currently reimbursed
Schaffini et al., ³⁷ 2016		
Smith et al., ³⁸ 2003		
Smith and Satyshur, ³⁹ 2016		
Wood et al., ⁴⁰ 2016		

^aEnablers and barriers synthesized by review authors.

successful implementation of pediatric teledabetes.^{20,39} Service models need to be convenient and have good usability to reduce the burden on patients and clinicians. Recupero et al.³⁶ improved the functionality of an intervention by enabling the automatic transfer of BGLs, rather than manual data entry. Teledabetes services, which included training for clinicians and patients, demonstrated the importance of ensuring that patients and clinicians understand the technology. In addition, having organizational support, technical support, and management assistance were considered essential for successful service implementation.

Teledabetes services also reported various challenges; technical issues negatively influenced patients' willingness to engage in pediatric teledabetes.^{1,27} Teledabetes services also impacted on clinicians' workflows and Carrol et al.¹ reported that nurse practitioners were giving feedback to patients outside of usual clinical hours. Others reported that teledabetes services were offered in addition to standard care, resulting in increased clinician workload.^{2,20} This was often in the absence of recognition from health services of the work and time involved with teledabetes, as well as funding for additional staff or appropriate remuneration.^{29,30,40}

There have been three other reviews of pediatric teledabetes.^{41–43} Our review was of broader scope as it included both type 1 and type 2 patients. The reviews by Guljas et al.⁴¹ and Shulman et al.⁴³ were limited to type 1 patients. Furthermore, we included all modes of teledabetes, whereas Deacon and Edirippulige⁴² only evaluated mHealth interventions and Shulman et al.⁴³ only examined remote monitoring.

We also identified key enablers and barriers to teledabetes service implementation, which was not discussed by Deacon and Edirippulige,⁴² Guljas et al.,⁴¹ and Shulman et al.⁴³ Guljas et al.⁴¹ concluded that teledabetes improved management of type 1 diabetes in pediatric patients. Shulman et al.⁴³ conducted a meta-analysis of pediatric teledabetes on glycemic control, finding that although teledabetes did not significantly improve HbA1c, it did not worsen glycemic control. We found that change in HbA1c results varied across studies, comparable with the findings by Deacon and Edirippulige,⁴² who reported mixed results for clinical effectiveness.

Implications for practice

It is important to understand how various pediatric teledabetes service models can best be integrated into routine clinical practice. The enablers and barriers identified in this review outlined logistical factors associated with the delivery of the service and the importance of ensuring that teledabetes services complemented conventional services. Remote monitoring was feasible, and the most common mode used, achieving improved diabetes monitoring. Real-time videoconference modes improved a patient's access to care, particularly given the limited number of health professionals who specialize in pediatric diabetes management. It has been demonstrated that pediatric teledabetes does not compromise clinical care as teledabetes did not worsen glycemic control.

Limitations

Many of the included studies had a short-term study period. The finding of HbA1c improvement requires long-term follow-up to assess the sustainability of results. Some of the

included studies also had small sample sizes, reducing the power of their results. Given that the articles were published between 2000 and 2019, the change in technology overtime needs to be acknowledged. We can draw no conclusion as to whether pediatric teledabetes is sustainable as there are no long-term studies of any service. Publication bias is also recognized as studies may be more likely to report positive outcomes favoring telehealth.

Conclusion

This review has demonstrated that pediatric teledabetes can be delivered by remote monitoring and real-time videoconference modes. The use of pediatric teledabetes increased interactions between patients and clinicians, improving access to specialized care and diabetes monitoring. Most patients, families, and caregivers expressed satisfaction with teledabetes services. In some situations, teledabetes improved glycemic control in the short term. Further research is still required to determine the long-term clinical benefit of teledabetes. Additional investigation into the cost-effectiveness of teledabetes will also have to be considered for future research.

Integration of teledabetes services with existing clinical workflows, dedicated staff, clinician and patient training, appropriate data security, technology with good usability, and the availability of technical support, would enable the positive outcomes of teledabetes services. Increased patient responsibilities and clinician workload, and technical issues are likely to act as barriers to teledabetes services.

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Supplementary Material

Supplementary Figure S1

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