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Effect of Wearable Technology on Metabolic Control and the Quality of Life in Children and Adolescents with Type 1 Diabetes: A Systematic Review and Meta-Analysis

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Background: Type 1 diabetes is one of the most common chronic diseases in children. Wearable technology (insulin pumps and continuous glucose monitoring devices) that makes diabetes management relatively simple, in addition to education and follow-ups, enhances the quality of life and health of individuals with diabetes.

Aims: To evaluate the impact of wearable technology on metabolic management and the quality of life in children and adolescents with type 1 diabetes.

Study Design: Systematic review and meta-analysis.

Methods: The Preferred Reporting System for Systematic Reviews and Meta-Analyses was used to conduct a systematic review and meta-analysis. PubMed, Web of Science, MEDLINE, Cochrane Library, EBSCO, Ulakbim and Google Scholar were searched in July 2022 and July 2023 using predetermined keywords. The methodological quality of the studies was evaluated using the Joanna Briggs Institute's Critical Appraisal Checklists for randomized controlled experimental and cross-sectional studies. The meta-analysis method was used to pool the data.

Results: Eleven studies published between 2011 and 2022 were included. The total sample size of the included studies was 1,853. The meta-analysis revealed that the decrease in hemoglobin A1C (HbA1c) level in those using wearable technology was statistically significant [mean difference (MD): -0.33, Z = 2.54, $p = 0.01$]. However, the technology had no effect on the quality of life [standardized mean difference (SMD): 0.44, Z = 1.72, $p = 0.09$]. The subgroup analyses revealed that the decrease in the HbA1c level occurred in the cross-sectional studies (MD: -0.49, Z = 2.54, $p = 0.01$) and the 12-19 (MD = 0.59, Z = 4.40, $p < 0.001$) and 4-18 age groups (MD: -0.31, Z = 2.56, $p = 0.01$). The subgroup analyses regarding the quality of life revealed that there was no difference according to the research design. However, the quality of life was higher in the wearable technology group than in the control group in the 8-12 and 4-18 age groups (SMD: 1.32, Z = 2.31, $p = 0.02$ and SMD: 1.00, Z = 5.76, $p < 0.001$, respectively).

Conclusion: Wearable technology effectively reduces the HbA1c levels in children and adolescents with type 1 diabetes in some age groups. However, it does not affect the quality of life.

INTRODUCTION

Type 1 diabetes is one of the most common chronic diseases in children, and an organized self-management strategy that includes regular blood sugar monitoring, physical activity, optimal nutrition, and insulin use must be followed.[1] The therapeutic goal for children with type 1 diabetes is to avoid or postpone acute and chronic complications while maintaining the quality of life.[2] Optimizing glycemic control in children with type 1 diabetes is crucial for neurocognitive and brain structure development, improvement of health-related aspects of life, and reduction of acute and chronic complications.[3]

Currently, wearable technology [insulin pumps and continuous glucose monitoring (CGM) devices] that makes diabetes management relatively simple, in addition to patient education and follow-ups, enhances the quality of life and health of children with diabetes.[4] In their systematic review and meta-analysis on the quality of life in

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children with type 1 diabetes utilizing an insulin infusion system, Rosner and Roman-Urrestarazu[5] analyzed 15 studies on the use of continuous subcutaneous insulin infusion (CSII) and multiple daily injections (MDI). They concluded that the hemoglobin A1C (HbA1c) levels were lower in patients using CSII than in patients using MDI. Furthermore, these patients demonstrated an improvement in the quality of life. The authors also demonstrated that the families of disabled children are more physically and psychologically vulnerable than families with healthy children, resulting in a decrease in their quality of life.

Wearable technology offers various advantages to individuals with type 1 diabetes by providing improved monitoring, management, and overall quality of life.[6] Wearable devices such as CGM systems can continuously monitor glucose levels in real-time. There is a need for frequent fingertip blood testing that allows for more comfortable and non-invasive monitoring. CGM systems provide alerts and alarms when glucose levels are too high or too low, permitting timely interventions and reducing the risk of dangerous blood sugar fluctuations. Connecting wearable insulin pumps to CGM systems can form a closed-loop system known as the "artificial pancreas." This integration optimizes blood glucose control and reduces the burden of manual insulin administration by allowing automatic insulin delivery based on real-time glucose readings. Wearable technology collects and stores vast amounts of data on glucose levels, insulin doses, physical activity and dietary patterns. This data allows individuals to make informed decisions regarding diabetes management, which leads to better metabolic control. Furthermore, wearable technology allows diabetes-related parameters to be monitored remotely by healthcare professionals, caregivers, or family members.[7] This monitoring allows timely response and support, especially in emergencies, or when blood glucose levels exceed the target range. Moreover, wearable technology can improve the quality of life of individuals with type 1 diabetes by eliminating frequent blood glucose measurements via the fingerstick method and insulin injections. Additionally, it offers more freedom and flexibility in daily activities.[8,9]

Although wearable technology provides significant benefits, it should always be used with the advice and guidance of medical professionals. Regular communication and collaboration with healthcare professionals remain essential for effective diabetes management.

According to studies on wearable technology in children and adolescents with type 1 diabetes, regular use of these devices has significantly and positively contributed to lowering HbA1c levels, preventing hypoglycemia attacks, and attaining an improved quality of life.[10-12] However, according to some studies, there is no clear evidence of a correlation between insulin pump therapy and the health-related quality of life in children with diabetes.[13,14]

A systematic critical evaluation of similar existing studies is required to bridge the gaps in literature and assess the impact of wearable technology on children for achieving of a good quality of life and metabolic management. In this study, we aimed to determine the effect of wearable technology (insulin pump and CGM devices) on metabolic control and quality of life in children and adolescents with type 1 diabetes.

Aim of the study and study questions

In this systematic review and meta-analysis we aimed to determine how wearable technology affects metabolic management and the quality of life in children and adolescents with type 1 diabetes. The following were the study questions to be addressed:

1. How does wearable technology affect the HbA1c levels in children and adolescents with type 1 diabetes?

2. How does wearable technology affect the quality of life of children and adolescents with type 1 diabetes?

MATERIALS AND METHODS

Ethics approval

Ethics committee approval was not required for this study because it was a meta-analysis study, which reanalyzes the data of published studies that have already been approved by ethics committees.

This study was carried out as a systematic review followed by a meta-analysis. Existing literature was retrospectively reviewed and data, analyses, and interpretations were systematically compiled. The PRISMA statement (Page et al.[15] or meta-analysis checklist on the items to be included in the writing of the research report) was followed for creating and writing the study protocol.

To avoid study duplication and limit the potential of bias, the study protocol was filed in the PROSPERO database (registration number: NR: CRD42022326378) on June 30, 2022, and revised on June 14, 2023.

Eligibility criteria

The studies were considered eligible on the basis of the following PICOS criteria:

Population (P): Children and adolescents with type 1 diabetes who were using wearable technology.

Interventions (I): Use of wearable technology (e.g., insulin pump, closed circuit insulin delivery systems, CGM system).

Comparators (C): Children and adolescents not using wearable technology (control group).

Outcomes (O): HbA1c level and quality of life.

Study design (S): Randomized controlled experimental and cross-sectional studies published in Turkish and English between 2010 and 2023 were included in the study.

Reviews and qualitative studies, studies published in languages other than Turkish and English, and studies whose full text could not be accessed were excluded from the analysis.

Screening strategy

The following databases were initially searched in July 2022 and updated in July 2023: PubMed, Web of Science, MEDLINE, Cochrane Library, EBSCO, Ulakbim, and Google Scholar. The following word groups were used in the searches: "(Diabetes Mellitus OR, Type I)

AND Child* OR Adolescent* AND (Insulin* OR Insulin Pump* OR Continuous Subcutaneous Infusion* OR Continuous Subcutaneous Injection*OR Wearable Technology*) AND (quality of life* OR HbA1c*) NOT (Diabetes Mellitus OR Type 2*)". The English keywords used were determined in accordance with "Medical Subject Headings (MESH)". An example of a PubMed search: (("diabetes mellitus"[MeSH Terms] OR ("diabetes"[All Fields] AND "mellitus"[All Fields]) OR ("diabetes mellitus"[All Fields]) OR Type[All Fields]) AND (("child"[MeSH Terms] OR "child"[All Fields]) OR ("adolescent"[MeSH Terms] OR "adolescent"[All Fields])} AND (("insulin"[MeSH Terms] OR "insulin"[All Fields]) OR (("insulin"[MeSH Terms] OR "insulin"[All Fields]) AND Pump[All Fields]) OR (Continuous[All Fields] AND ("infusions, subcutaneous"[MeSH Terms] OR ("infusions"[All Fields] AND "subcutaneous"[All Fields]) OR "subcutaneous infusions"[All Fields] OR ("subcutaneous"[All Fields] AND "infusion"[All Fields]) OR "subcutaneous infusion"[All Fields]) OR (Continuous[All Fields] AND ("injections, subcutaneous"[MeSH Terms] OR ("injections"[All Fields] AND "subcutaneous"[All Fields]) OR "subcutaneous injections"[All Fields] OR ("subcutaneous"[All Fields] AND "injection"[All Fields]) OR "subcutaneous injection"[All Fields])) OR ("wearable electronic devices"[MeSH Terms] OR ("wearable"[All Fields] AND "electronic"[All Fields] AND "devices"[All Fields]) OR "wearable electronic devices"[All Fields] OR ("wearable"[All Fields] AND "technology"[All Fields]) OR "wearable technology"[All Fields]) AND (("quality of life"[MeSH Terms] OR ("quality"[All Fields] AND "life"[All Fields]) OR "quality of life"[All Fields]) OR ("glycated hemoglobin"[MeSH Terms] OR ("glycated"[All Fields] AND "hemoglobin"[All Fields]) OR "glycated hemoglobin"[All Fields] OR "HbA1c"[All Fields])) AND ("2010/01/01"[PubDate]:"2023/06/30"[PubDate]). The reference lists of the studies included in the meta-analysis and that of previous meta-analyses were checked for additional studies to be screened.

Selection of studies

After excluding the duplicate studies from search results, the title, abstract, and full text of the articles were evaluated for eligibility. Disagreement between the two investigators about a particular study were resolved by reaching a consensus following a joint discussion. The PRISMA flowchart depicts the total number of studies screened, found eligible for meta-analysis, and excluded and the reasons for excluding certain studies (Figure 1).

Assessment of the methodological quality of studies

The methodological quality of the studies included in this meta-analysis was assessed using the Joanna Briggs Institute's (JBI) Critical Appraisal Checklist for randomized controlled experimental and cross-sectional studies.[16] The checklist includes 13 questions for experimental studies and eight questions for cross-sectional studies. The response options for the questions are "Yes," "No," "Uncertain," and "Not applicable." The methodological quality of the included studies was considered "mediocre" if < 50% of the items were answered "yes," "moderate" if 51-80% of the items were answered "yes," and "good" if > 80% of the items were answered "yes." The quality was assessed independently by both investigators, and the studies were combined in a single text for joint sessions.

Data extraction

The data extraction tool produced by JBI and available from its website was utilized to extract study data and make relevant alterations to the study. Using this data extraction tool, the methods used to obtain data on the place and year of the studies included in the meta-analysis, data sources utilized, sample size, use of an insulin pump, GCM, HbA1c level, and quality of life were gathered along with the main study results. The research data were analyzed independently by both investigators.

Pilot study

To prevent the risk of possible bias, the investigators, who met at each stage of the study, created a standard road map for conducting the pilot study for article screening, article selection, data extraction, and quality assessment of the included articles. Furthermore, both investigators carried out all the steps independently to prevent possible errors. The selected studies were combined in a single text for the joint sessions.

Ethical aspects

Because the studies used in the meta-analysis were open-access articles, permission from the individual authors was not obtained, and the data were used by citing the articles.

Statistical analysis

After pooling the gathered data, Review Manager (version: 5.4.1; The Nordic Cochrane Centre, Copenhagen, Denmark) was utilized for the meta-analysis. Heterogeneity between studies was assessed using the Tau^2, Cochran's Q, and I^2 statistics. An I^2 of 0-40%, 30-60%, 50-90%, and 75-100% indicated non-important, moderate, substantial, and considerable heterogeneity, respectively.[17] An I^2 of > 50% was considered significant heterogeneity. If I^2 was > 50%, a random effects model was used. However, if I^2 was ≤ 50%, a fixed effects model was used. The continuous variables of the study were quality of life and HbA1c level. Because these variables were evaluated with different measurement tools, the SMD was calculated for the quality of life, and the mean difference (MD) was calculated for the HbA1c level. All the tests were two-tailed, and a p value of < 0.05 was considered statistically insignificant. Additionally, in the sensitivity analysis, subgroup analyses were performed for quality of life and HbA1c level according to the participants' age groups and the study designs.

RESULTS

Search results

The initial database search identified 3,442 studies, and the subsequent review of additional sources revealed five studies. After excluding redundant data, titles, and abstracts, the full text of 25 articles were analyzed according to the inclusion criteria. Finally, 11 articles were included in the analysis (Figure 1).

Characteristics of the studies and study participants

Of the 11 studies included in the systematic review and meta-analysis, five were randomized controlled experimental studies,[2,18-21] and six were cross-sectional studies.[22-27] The studies were conducted in 2007-2022 and published in 2011-2022. However, the year of the study was not reported in three studies.[18,21,27] The studies were conducted in Australia,[18,19,21] Germany,[2] Saudi Arabia,[22,23] Sweden,[20] Denmark,[24] Italy,[25] Hungary,[27] and Türkiye.[26] The total sample size of the included studies was 1,853 (wearable technology group, n = 869; control group, n = 984). The age of the participants in the studies ranged from 1 to 25 years (Table 1).

Characteristics of the intervention

Interventions such as stopping the pump before the onset of hypoglycemia, providing sensor support, and early or late application, comparison of the pump and MDIs, and the use of algorithms were employed in the included studies (Table 1).

Study quality assessment results

Among the randomized controlled experimental studies, one was of good quality and four were of moderate quality. Among the cross-sectional studies, three were of good quality and three were of moderate quality (Table 2). In the randomized controlled experimental studies, issues were primarily observed during blinding, and in the cross-sectional studies, issues were related to identifying and managing confounding/contributing factors.

Meta-analysis of data related to HbA1c level

In eight studies, the HbA1c levels of patients using wearable technology were compared with those of the controls.[2,18-20,22,25-27] The meta-analysis revealed that wearable technology caused a statistically significant decline in HbA1c levels (MD: -0.33, Z = 2.54, $p = 0.01$; Figure 2). In the subgroup analysis according to study design, the significant effect was seen in the cross-sectional studies (MD: -0.49, Z = 4.54, $p = 0.01$; Figure 3). In the subgroup analyses according to the participant age groups, a significant effect was observed in the 12-19 (MD: 0.59, Z = 4.40, $p < 0.001$) and 4-18 (MD: -0.31, Z = 2.56, $p = 0.01$) age groups (Figure 4).

Meta-analysis of data related to the quality of life

In 10 studies, data regarding the quality of life of children or adolescents using wearable technology and that of the controls were reported.[2,18,19,21-27] The meta-analysis revealed that the difference in the quality of life between those using wearable technology and the controls was not statistically significant (SMD: 0.44, Z = 1.72, $p = 0.09$; Figure 5). This was consistent with the results of the subgroup analyses according to the study design (randomized controlled experimental study: SMD: 0.20, Z = 0.49, $p = 0.14$ vs. cross-sectional study: SMD: 0.62, Z = 1.49, $p = 0.14$) (Figure 6).

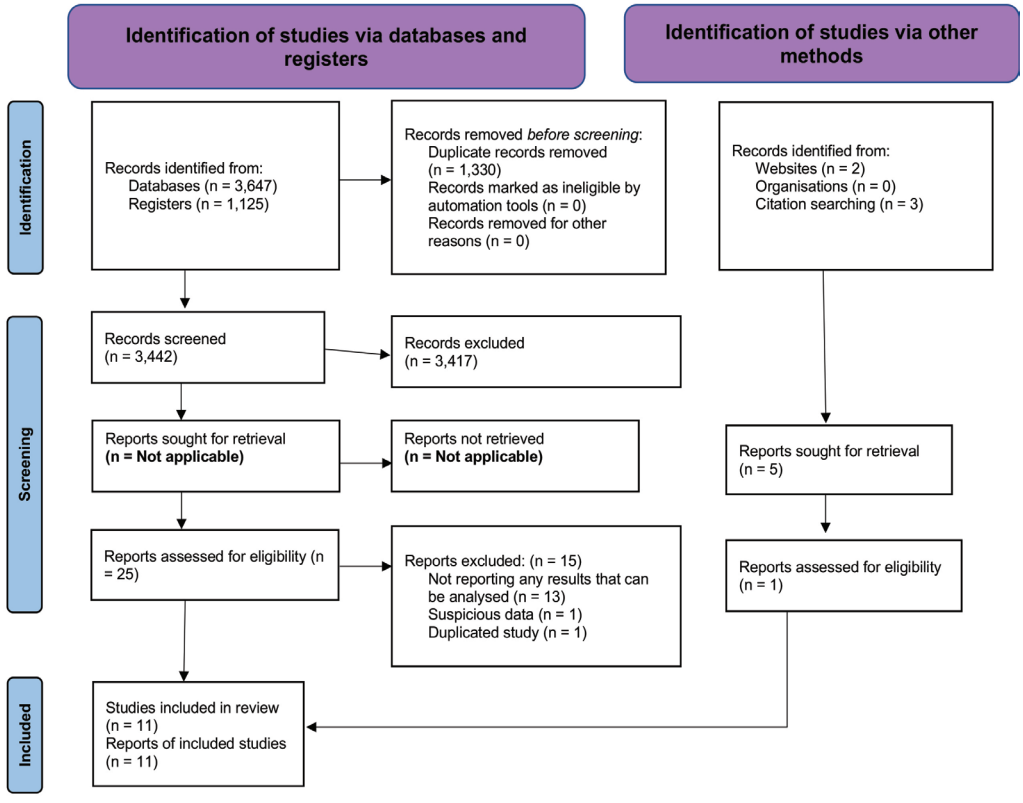

FIG. 1. PRISMA 2020 flow diagram.

PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis.

TABLE 1. Characteristics and Main Findings of the Included Studies.

Author(s); year, country	Study design/ place of study	Data collection tool	Data collection year	Sample size	Intervention type (wearable technology) and its features	Average age, year (SD)	Main outcomes
Abraham et al.[18]; 2018, Australia	RCT/Home Trial	PedsQL	No information	Intervention (PLGM): (n = 80); Control (SAPT): (n = 74)	Insulin pump	Intervention: 13.1 ± 2.8 Control: 13.3 ± 2.8 Total: 13.2 ± 2.8 Range, 8-20 years	HbA1c quality of life
Abraham et al.[19]; 2021, Australia	RCT/Pediatric Diabetes Center	HbA1c PedsQL	2017-2019	Intervention (HCL): (n = 58); Control (CSII or MDI with or without CGM): (n = 53)	Hybrid closed-loop (HCL); Insulin pump	12-25 years < 18 years ≥ 18 years	HbA1c quality of life
Al Hayek et al.[22]; 2017, Saudi Arabia	CSS/Diabetes Treatment Center	PedsQL 3.0	2017	Intervention (CSII): (n = 18); Control (MDI): (n = 29)	Insulin pump	13-19 years	HbA1c quality of life
Al Shaikh et al.[23]; 2020, Saudi Arabia	CSS/Pediatric Service	PedsQL 3.0	2016	Intervention (CSII): (n = 34); Control (MDI): (n = 34)	Insulin pump	0-18 years MDI: 12.9 ± 2.8 CSII: 14.6 ± 2.5	Quality of life
Birkebaek et al.[24]; 2014, Denmark	CSS/Web-based	HbA1c PedsQL-DM PedsQL-GCS	2009	Intervention (CSII): (n = 295); Control (MDI): (n = 405)	Insulin pump (early-late use)	8-17 years CSII: 12.9 ± 2.6 MDI: 13.6 ± 2.6	Quality of life
Brorsson et al.[20]; 2019, Sweden	RCT/Children's Hospital	HbA1c	2012-2013	Intervention (CSII + GSD-Y): (n = 37); Control (CSII): (n = 32)	Guided self-determination (GSD-Y) (training with insulin pump)	12-18 years	HbA1c
Franceschi et al.[25]; 2022, Italy	CSS/Pediatric Diabetology Outpatient Clinic	PedsQL 3.0	2017-2022	Intervention (group A: early use of CGM): (n = 85); Control (late use of group B - 1 year after diagnosis): (n = 67)	Sensor (early-late use)	4-18 years	Quality of life HbA1c
Jenkins et al.[21]; 2011, Australia	RCT/Unspecified	DQOLY	No information	Group A (intervention: CSII/RT - CGM with algorithm): (n = 28); Group B (control: CSII/RT - CGM without algorithm): (n = 27)	Insulin pump (algorithm)	Adolescents over 13 years of age; Group A: n = 11 (16.6 ± 1.3) Group B: n = 11 (16.6 ± 1.5)	Quality of life
Kardaş and Gürol[26]; 2022, Türkiye	CSS/Child Endocrinology Outpatient Clinic	HbA1c PedsQL	2020-2021	Intervention (insulin pump): (n = 40); Control (insulin pen): (n = 40)	Insulin pump	8-12 years	HbA1c PedsQL
Lukács et al.[27]; 2013, Hungary	CSS/Diabetes Summer Camps	PedsQL 4.0 HbA1c	No information	Intervention (CSII): (n = 104); Control (MDI): (n = 135)	Insulin pump	8-18 years CSII: 13.29 ± 2.85 MDI: 13.44 ± 2.90	Quality of life
Mueller-Godeffroy et al.[2]; 2018, Germany	RCT/Pediatric Diabetes Center	KINDL-DM HbA1c	2011-2014	Intervention (CSII): (n = 90); Control (MDI): (n = 89)	Insulin pump	6-16 years CSII: 11.3 ± 2.7 MDI: 11.9 ± 2.8	Quality of life HbA1c

PedsQL DM, Pediatric Quality of Life Inventory (PedsQL) 3.0 Diabetes Module; PedsQL GCS, Pediatric Quality of Life Inventory (PedsQL) 4.0 Generic Core Scale (GCS); DQOL-Y, Diabetes Quality of Life for Youth Questionnaire; CSII, Continuous subcutaneous insulin infusion; PLGM, SAPT + Suspend before low; FGM, Flash glucose monitoring; GSD-Y, Guided self-determination-young; isCGM, intermittently scanned continuous glucose monitoring; Abbott FreeStyle Libre 1® Glucose Monitoring System; CSII, Continuous subcutaneous insulin infusion; CGM, Continuous glucose monitoring; SAPT, Sensor-augmented pump therapy; SAP (Paradigm Real-Time Insulin Pump and Continuous Glucose Monitoring System, Medtronic MiniMed, Northridge, CA, USA); CSII, MiniMed Paradigm 515/715 insulin pumps (Medtronic MiniMed); KIDSCREEN, Children questionnaire of health-related quality of life; KINDL-DM, Diabetes specific quality of life; MDI, Multiple daily injections.

However, in the subgroup analyses according to the participant age groups, the quality of life was higher in the wearable technology group than in the control group in the age groups of 8-12 years (SMD: 1.32, Z = 2.31, $p = 0.02$) and 4-18 years (SMD: 1.00, Z = 5.76, $p < 0.001$) (Figure 7).

TABLE 2. Quality Assessment Scores of the Studies.

Studies	JBI critical appraisal checklist questions for randomized controlled trials													Qualityscore
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	
Abraham et al.[18]; 2018	Y	N	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Medium (69.2%)
Abraham et al.[19]; 2021	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Good (84.6%)
Brorsson et al.[20]; 2019	Y	B	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Medium (69.2%)
Jenkins et al.[21]; 2011	B	B	Y	B	N	N	Y	Y	Y	Y	Y	Y	Y	Medium (61.5%)
Mueller-Godeffroy et al.[2]; 2018	Y	B	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Medium (69.2%)
Question quality score	60.0%	0.0%	80%	0.0%	0.0%	40.0%	100%	100%	100%	100%	100%	100%	100%	
Studies	**JBI critical appraisal checklist questions for cross-sectional studies**													
	S1	S2	S3	S4	S5	S6	S7	S8						
Al Hayek et al.[22]; 2017	Y	Y	Y	Y	N	N	Y	Y						Medium (75.0%)
Al Shaikh et al.[23]; 2020	Y	Y	Y	Y	N	N	Y	Y						Medium (75.0%)
Birkebaek et al.[24]; 2014	Y	Y	Y	Y	N	N	Y	Y						Medium (75.0%)
Franceschi et al.[25]; 2022	Y	Y	Y	Y	Y	N	Y	Y						Good (87.5%)
Kardaş and Gürol[26]; 2022	Y	Y	Y	Y	Y	N	Y	Y						Good (87.5%)
Lukács et al.[27]; 2013	Y	Y	Y	Y	Y	Y	Y	Y						Good (100.0%)
Question quality score	100%	75.0%	75.0%	75.0%	100%	100%	75.0%	100%						

Y, yes; N, No; U, not applicable; B, undetermined Contributions of Authors. "JBI critical appraisal checklist questions for randomized controlled trials (Appendix 1)" and "JBI critical appraisal checklist questions for cross-sectional studies (Appendix 2) "were used in the quality assessment of the studies.

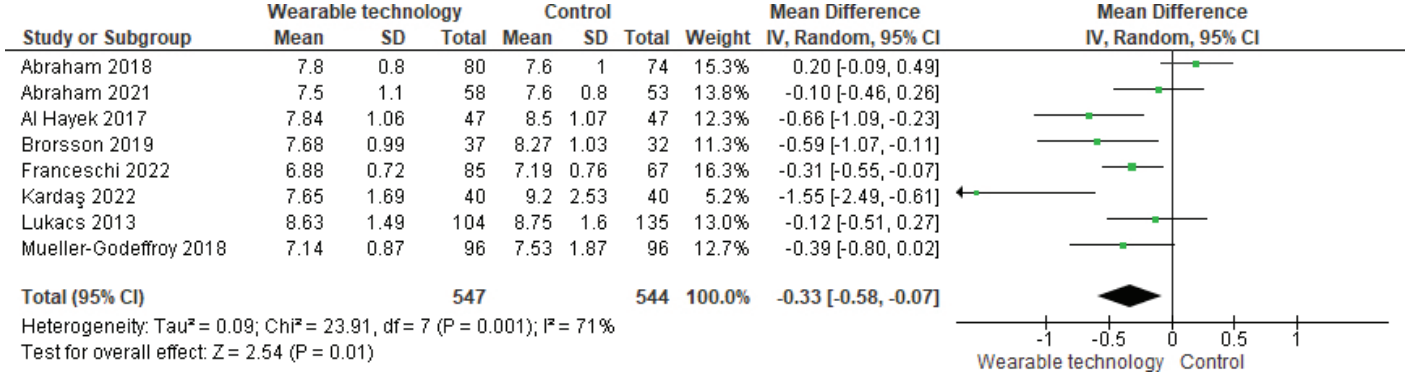

FIG. 2. Meta-analysis of HbA1c level in the wearable technology and control groups.
CI, confidence interval; SD, standard deviation; HbA1c, hemoglobin A1C.

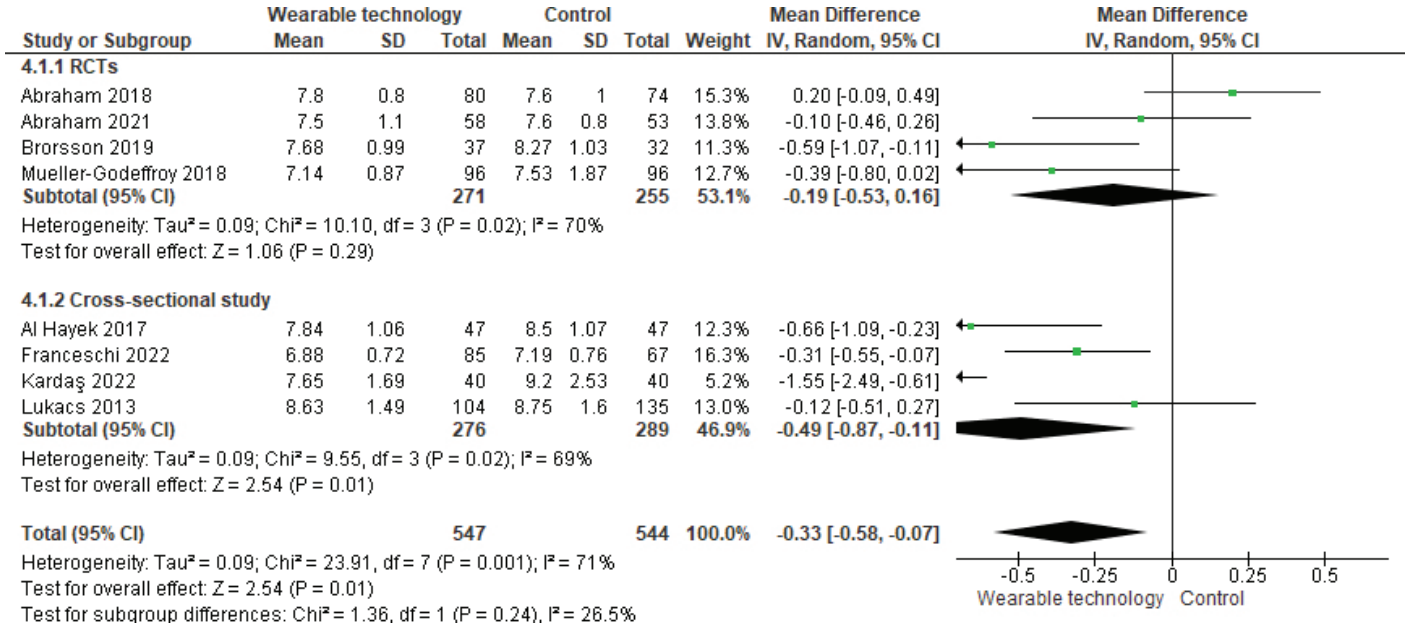

FIG. 3. Subgroup analyses of the HbA1c level in the wearable technology and control groups according to the study design.
CI, confidence interval; SD, standard deviation; HbA1c, hemoglobin A1C; RCT, randomized controlled trials.

DISCUSSION

In this systematic review and meta-analysis, we have presented the findings of 11 studies to explore the impact of wearable technology on metabolic management and the quality of life in children and adolescents with type 1 diabetes. We found that although wearable technology effectively lowered HbA1c levels, it did not influence the quality of life outcomes. These findings indicate that wearable technology can be used in routine care settings with fewer invasive procedures.

In this study, we found that the use of wearable technology lowered the HbA1c levels in children and adolescents with type 1 diabetes. Moreover, in the subgroup analysis according to the study design, this significant influence was observed in the cross-sectional studies. In the subgroup analysis according to the participant age groups, wearable technology effectively reduced HbA1c levels in the 8-11, 12-19, and 4-18 age groups. Isganaitis et al.[28] examined the glycemic control of diabetic individuals aged 14-18 and 18-25 years. Among the individuals under the age of 18, 31 use used a closed-loop control (CLC) system and 17 used a sensor-augmented pump technology. The CLC system demonstrates significant potential in maintaining the HbA1c level within the normal limits in patients of all age groups. Sherr et al.[29] conducted a study on 80 children aged 2-5.9 years who were using insulin technology. They found that the technological devices safely and effectively achieved glycemic control. Messer et al.[30] examined the effect of a bionic pancreas (n = 112) and CGM (n = 53) on diabetes control in children aged 6-17 years. They determined that the use of a bionic pancreas had a more positive effect on HbA1c levels than CGM, and that CGM had a more positive effect than standard care. Similar to the findings in literature, we found that wearable technology was effective in reducing HbA1c levels in the 8-11, 12-19, and 4-18 age groups. This finding is significant when the acute and chronic complications of diabetes and prevention strategies are considered. In Sweden, Fureman et al.[31] compared the HbA1c level, incidence of hypoglycemia, and body mass index of children with type 1 diabetes using CSII with those of children using MDI. The study grouped the children by age as follows: 0-6-year-olds, 7-12-year-olds, and 13-17-year-olds. In children aged 0-6 years and 7-12 years, the HbA1c level was lower in the CSII group than in the MDI group. The mean HbA1c level was higher in boys aged 13-17 years than in boys of other ages only in the CSII group. However, there was no significant difference in the mean HbA1c level between the CSII and MDI groups. Ross and Neville[32] compared the HbA1c level and quality of life of children using MDI and CSII in 15 randomized controlled trials. They found that the HbA1c level significantly decreased (-0.18 to -0.7%) and the quality of life significantly increased in children using CSII, when compared with children using MDI. However, there was no significant difference in HbA1c level across the groups. Our study results were similar to these results.[31,32] Teo et al.[33] examined and analyzed 21 randomized controlled trials that assessed the effectiveness of CGM in maintaining glycemic control in individuals with type 1 diabetes. In the study, the incidence of HbA1c, hypoglycemia, and ketoacidosis was examined. They determined that although CGM had a positive effect on glycemic control, there was no statistically significant difference in the result. In a meta-analysis study of individuals with type 1 diabetes, CGM and self-monitoring of blood glucose (SBMG) were compared in addition to the HbA1c levels of the CGM + CSII and SMBG + MDI groups. The HbA1c levels of the CGM and CGM + CSII groups were significantly lower than the HbA1c levels in the SBMG and SMBG + MDI groups.

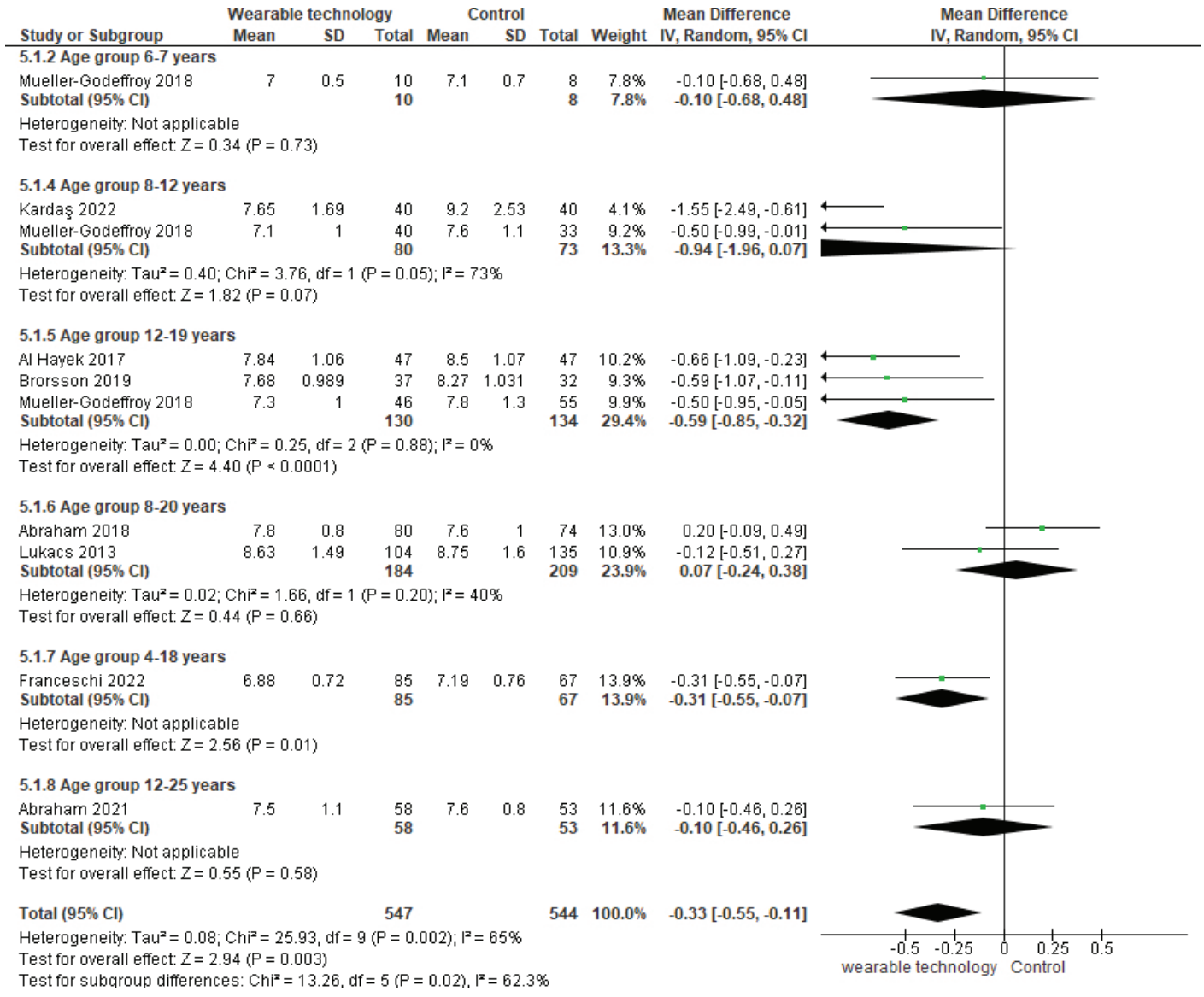

FIG. 4. Subgroup analyses of the HbA1c of level in the wearable technology and control groups according to age groups.
CI, confidence interval; SD, standard deviation; HbA1c, hemoglobin A1C.

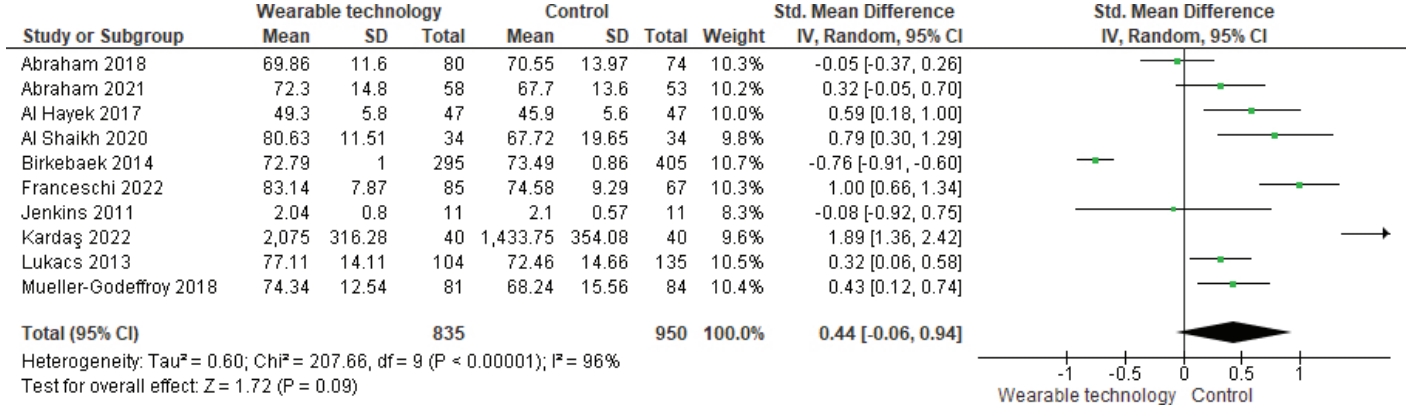

FIG. 5. Meta-analysis of the quality of life in the wearable technology and control groups.
CI, confidence interval; SD, standard deviation; RCT, randomized controlled trials.

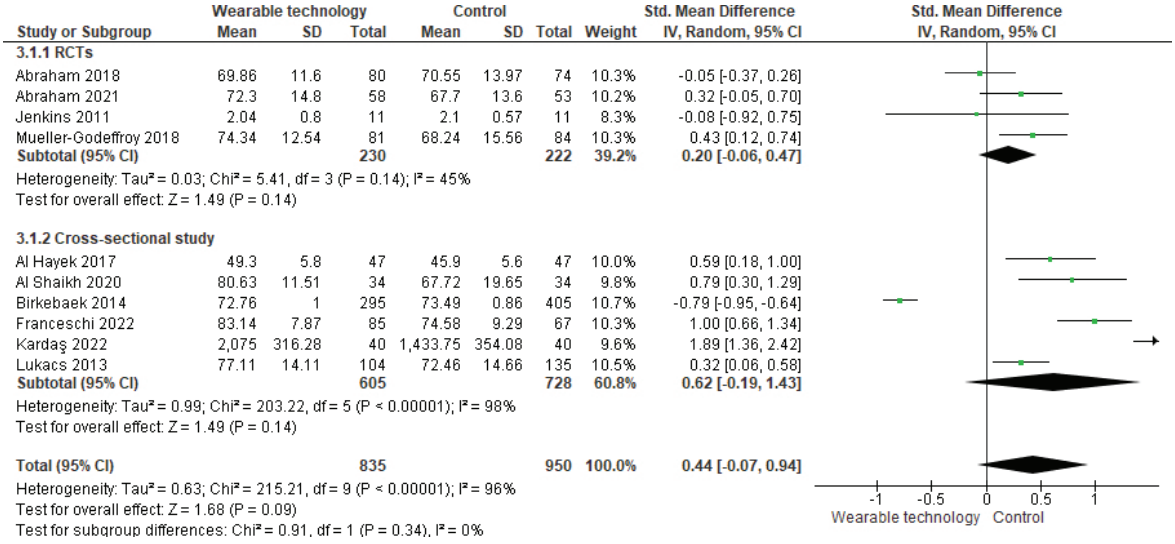

FIG. 6. Subgroup analyses the quality of life in the wearable technology and control groups according to study design.
CI, confidence interval; SD, standard deviation.

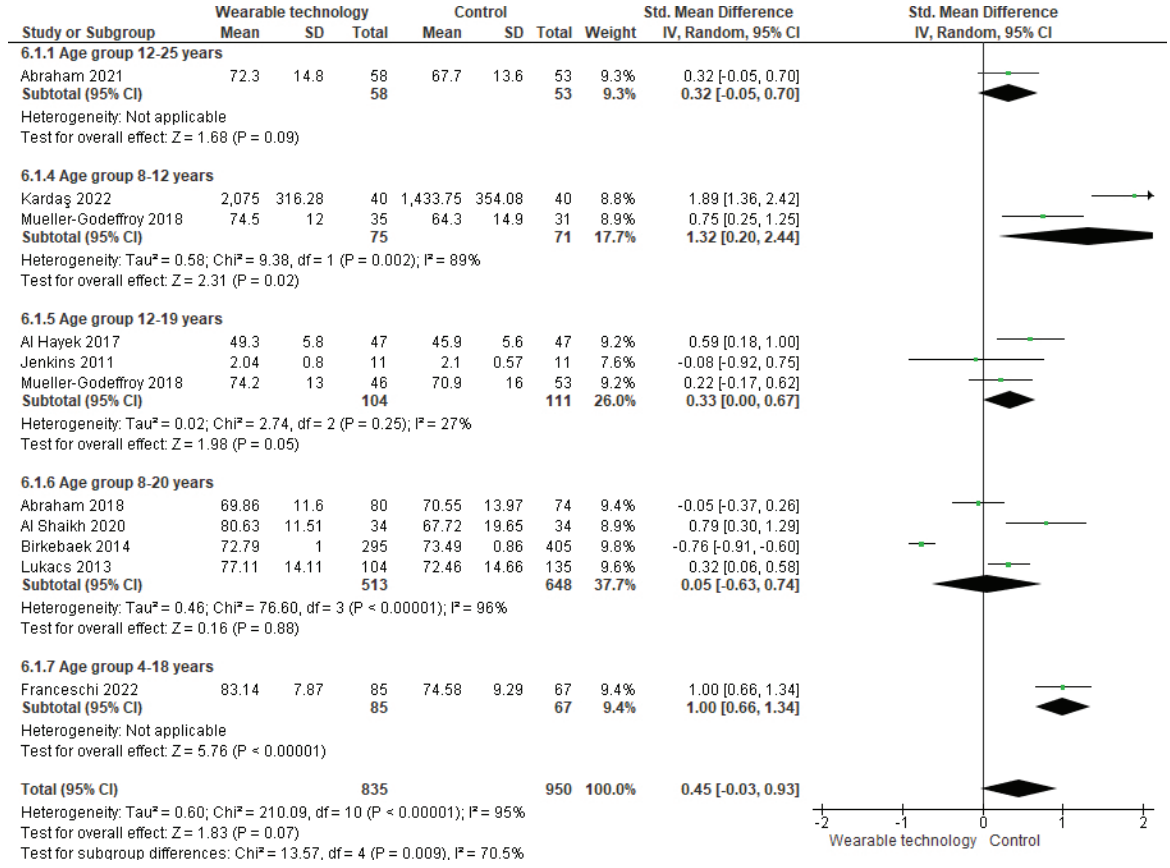

FIG. 7. Subgroup analyses of the quality of life in the wearable technology and control groups according to age groups.
CI, confidence interval; SD, standard deviation.

However, there was no statistically significant difference between the groups.[34] Bekele et al.[10] and Ng et al.[12] also found that children using wearable technology had lower HbA1c levels than those receiving multiple injections. The results obtained in our study are consistent with those of the literature. Children using wearable technology have lower HbA1c levels that those using MDI due to the more frequent blood glucose monitoring.

In our study, we found that the use of wearable technology improved the quality of life in children and adolescents with type 1 diabetes. However, there was no significant difference between the groups. Gianini et al.[11] used an advanced hybrid CLC system to evaluate 24 children and adolescents with type 1 diabetes. They determined that the use of the CLC system decreased the fear of hypoglycemia and emotional stress and improved the quality of life. In the study by Ng et al.[12], the HbA1c level decreased and the quality of life increased in children using the advanced hybrid CLC system. However, there was no statistically significant difference.

According to our meta-analysis, the effect of wearable technology on the quality of life in children and adolescents with type 1 diabetes was similar in randomized controlled experimental studies and observational trials. Nivet et al.[35] discovered similar results in their study on children aged 10-17 years with type 1 diabetes. They did not find a significant difference in quality of life between children who used a tubeless patch pump and those who received numerous injections.

In our study, the effect of wearable technology on the quality of life of children and adolescents with type 1 diabetes was similar in the 12-19 and 8-20 age groups. However, wearable technology was effective in increasing the quality of life in children in the age groups of 4-18 and 8-11 years. Bratke et al.[36] examined the HbA1c levels and quality of life of children aged 10-17 years who used CGM and insulin pumps. They reported that the use of these devices were not positively correlated with the patient's quality of life.

The lack of difference between the quality of life of children using wearable technology and that of children using MDI or measuring blood glucose via the fingerstick method may be related to the adaptation of children to new technologies. Adaptation to a new technology is a long process for some individuals. During the adaptation process, the child with type 1 diabetes and their family need support, particularly from healthcare professionals. We believe that this process of adaptation may delay the improvement in the child's quality of life. Individual differences should be accounted for when considering the use of wearable technology for children with type 1 diabetes. These individual characteristics may account for the differences in quality of life and the use of wearable technology in different age groups. Furthermore, a child may not want to give up the systems (e.g., fingerstick blood glucose measurement and MDI) that he/she are accustomed to.

The strengths of this systematic review and meta-analysis were the broad availability of systematic reviews, the fact that the majority of the studies examined were up-to-date and conducted in developed countries, including Europe, and the moderate-to-good quality of the studies. Another strength of the study was that the HbA1c level and the quality of life included in the analysis were determined by concrete and measurable methods. However, a limitation of this meta-analysis was that only studies published in English were included. Furthermore, some of the meta-analysis studies included only a small number of studies with small sample sizes and demonstrated high heterogeneity between studies. This may have weakened the strength of the results. In order to control this effect, the random effects model was selected if I^2 was > 50%.

This study revealed that wearable technology effectively reduces HbA1c levels in children and adolescents with type 1 diabetes. This significant effect was observed in cross-sectional studies and in the 12-19 and 4-18 age groups. We also determined that wearable technology did not influence the quality of life outcomes in children and adolescents with type 1 diabetes, and this finding was seen in randomized controlled experimental and cross-sectional studies. However, although wearable technology demonstrated a similar effect on the quality of life in the 12-19, 12-25, and 8-20 age groups, it effectively improved the quality of life in the 4-18 and 8-12 age groups.

These findings indicate that the use of wearable technology in children and adolescents with type 1 diabetes can be expanded on the basis of patient preferences. Furthermore, healthcare professionals should be informed and made aware during formal and informal training that wearable technologies is an option for children and adolescents with type 1 diabetes. Health service managers can design their policies in a manner that supports the use of wearable technologies and integrates these techniques into the care services offered to children with type 1 diabetes. More comprehensive randomized controlled trials are required to explore the effectiveness of wearable technology. Furthermore, qualitative studies should be conducted to determine the actual experiences of patients in this context.

Ethics Committee Approval: Ethics committee approval was not required for this study because it was a meta-analysis study, which reanalyzes the data of published studies that have already been approved by ethics committees.

Data Sharing Statement: The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Authorship Contributions: Concept- Ç.Ç.Ö.; Design- Ç.Ç.Ö.; Supervision- Ç.Ç.Ö.; Materials- Ç.Ç.Ö.; Data Collection or Processing- F.Y.; Analysis or Interpretation- F.Y., Ç.Ç.Ö; Literature Search- F.Y.; Writing- F.Y., Ç.Ç.Ö.; Critical Review- F.Y., Ç.Ç.Ö.

Conflict of Interest: The authors declare that they have no conflict of interest.

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Appendix 1: http://balkanmedicaljournal.org/uploads/pdf/appendix--1.pdf

Appendix 2: http://balkanmedicaljournal.org/uploads/pdf/appendix--2.pdf

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