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Diabetes care practices and outcomes in 40.000 children and adolescents with type 1 diabetes from the SWEET registry during the COVID-19 pandemic

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ABSTRACT

Aims: This study aimed to provide a global insight into initiatives in type 1 diabetes care driven by the COVID-19 pandemic and associations with glycemic outcomes.
Methods: An online questionnaire regarding diabetes care before and during the pandemic was sent to all centers (n = 97, 66,985 youth with type 1 diabetes) active in the SWEET registry. Eighty-two responded, and 70 (42,798 youth with type 1 diabetes) had available data (from individuals with type 1 diabetes duration >3 months, aged ≤21 years) for all 4 years from 2018 to 2021. Statistical models were adjusted, among others, for technology use.
Results: Sixty-five centers provided telemedicine during COVID-19. Among those centers naive to telemedicine before the pandemic (n = 22), four continued only face-to-face visits. Centers that transitioned partially to telemedicine (n = 32) showed a steady increase in HbA1c between 2018 and 2021 ($p < 0.001$). Those that transitioned mainly to telemedicine (n = 33 %) improved HbA1c in 2021 compared to 2018 ($p < 0.001$).
Conclusions: Changes to models of care delivery driven by the pandemic showed significant associations with HbA1c shortly after the pandemic outbreak and 2 years of follow-up. The association appeared independent of the concomitant increase in technology use among youth with type 1 diabetes.

Abbreviations: BMI, SDS body mass index standard deviation score calculated using the World Health Organization reference values; CGM, use of continuous glucose monitoring; CPCG, Clinical Practice Consensus Guidelines; DID, Daily Insulin Dose; DKA, diabetes ketoacidosis; HbA1c, haemoglobin A1c; ISPAD, International Society for Pediatric and Adolescent Diabetes; SH, severe hypoglycemia; SWEET, Better control in Pediatric and Adolescent diabeteS: Working to crEate CEnTers of Reference.

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[1] A complete list of contributing centers for the SWEET Study Group can be found in the Appendix.

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1. Introduction

The COVID-19 pandemic, due to lockdowns of variable extent and duration in different countries, forced the modification of pediatric care worldwide [1–3]. Medical teams, including multidisciplinary teams for diabetes care, addressed these challenges [4–6]. Traditional models of diabetes care once delivered routinely in person, were forced to adopt a diverse array of ad hoc solutions during the pandemic [7,8].

Over the past few years, a significant increase in telemedicine use (also: digital/virtual clinic, remote monitoring, and telecare) in pediatric diabetes care has been observed. Advances in continuous glucose monitoring (CGM) technology, increased clinical uptake, and cloud-based data exchange, have decisively contributed to and accelerated this advancement [8,9] and were swiftly incorporated in many institutions with the pandemic outbreak [4,10,11].

The results of these rapidly and unscheduled implemented changes, under the restraints of healthcare systems and real-time regulations to the COVID-19 pandemic, were challenging to predict and caused uncertainty for care providers and consumers [5,12]. Initially, there was concern about the potential to impact glycemic outcomes negatively, but the majority of reports published to date have demonstrated stable glycemic control among youth with type 1 diabetes [13–16]. Some authors even noted temporary improvements in glycemic control [15,17–19].

Furthermore, there is increasing evidence that diabetes care teams [10,20] and individuals with type 1 diabetes [12] seem to be satisfied with telemedicine. However, evidence from extensive multinational, multicultural studies is still being determined.

Our study primarily focused on changes in pediatric ambulatory and inpatient type 1 diabetes care driven by the COVID-19 pandemic, including telemedicine and psychological support, and their potential associations with HbA1c and acute diabetes complications. The study aim was pursued using data from centers from the international pediatric SWEET registry, providing an over-arching, international insight into different diabetes practices.

2. Subjects, materials and Methods

2.1. Materials and methods

Data from individuals with type 1 diabetes, aged ≤21 years, and with type 1 diabetes duration >3 months were extracted from the SWEET database. For each individual, the following data were aggregated: current age, age at diagnosis, biological sex, diabetes duration, HbA1c [mmol/mol] and [%], use of insulin pump and use of CGM (including both real-time and intermittently scanned glucose monitoring; as binary variables), the prevalence of diabetic ketoacidosis (DKA at diabetes onset was not taken into account) and severe hypoglycemia (SH), body mass index standard deviation score (BMI SDS) calculated using the World Health Organization reference values [21] and daily insulin dose [U/kg] (DID). DKA (pH < 7.3 or serum bicarbonate < 15 mmol/l) and SH (event during which assistance of another person is required to administer carbohydrates, intravenous glucose, or glucagon) followed the definitions presented in the ISPAD 2022 Clinical Practice Guidelines [22,23]. The proportion of individuals with at least one event in the respective treatment year was analyzed.

Additionally, a short, structured questionnaire regarding diabetes care and telemedicine was sent online (Google Forms, Google LLC, California, United States) between November 2020 and January 2021 to all centers that were active in the SWEET registry at that time (97 centers worldwide, overall 66,985 children with type 1 diabetes). The survey is available in detail in the online Supplementary materials.

To capture fixed trends in glycemic control potentially associated with changes to diabetes care delivery, we applied a prolonged observation period – two years before the pandemic and the first two years of the pandemic. This interval selection was supported by the ability to visualize the results of not only the moment of the pandemic outbreak and first wave of lockdowns but also to capture longer-term changes in diabetes care provided to children and adolescents with type 1 diabetes.

2.2. Statistical analysis

To compare the pre-pandemic and pandemic period from 2018 to 2021, data were aggregated by individual and by year. Continuous variables were presented as median with lower and upper quartiles, and binary variables as percentages in descriptive analyses. Repeated measurements linear and logistic regression models with a banded autoregressive covariance (Toeplitz) structure [24] were used to study outcomes associated with diabetes care practices. All models were adjusted for sex, age (categorized as <6, 6 to <12, 12 to <18, ≥18 years), diabetes duration (categorized as <2, 2 to <5, 5 to <10, and ≥10 years), treatment modality (with or without insulin pump, with or without CGM) use (per each year) and the SWEET regions [25]. In addition, an interaction term between the year and the respective diabetes care practice was included. Regression results were presented as adjusted least square means or frequencies with 95 %-confidence intervals. SAS version 9.4 (build TS1M7, SAS Institute Inc, Cary, NC) was used for statistical analyses, and a two-sided p-value < 0.05 was considered statistically significant.

3. Results

3.1. Registry data from 2018 to 2021 for centers that shared information on changes in pediatric diabetes care provision

A summary of the data cumulatively and by year throughout the 4-year observation period between 2018 and 2021 is presented in Table 1. Median HbA1c was lower in 2021 by 0.2 % (1 mmol/mol) compared to 2018, $p < 0.001$. The insulin pump and CGM use significantly increased by 7.8 % and 22.3 % during the observational period, respectively ($p < 0.001$). The gender distribution and the proportions of participants with at least one SH or DKA were stable. The median number of data uploads per person with type 1 diabetes sent to the SWEET database by centers decreased from 3 to 2 annually during the pandemic.

3.2. Changes in the provision of pediatric diabetes care by centers

Out of the 82 (85 %) centers that responded to the survey, data for the whole studied period (2018–2021) were available for 70 (72 % of all SWEET centers). Only these 70 centers were included in the analysis.

Proportions of centers and individuals in the centers were divided into four groups (Fig. 1): telemedicine offered before the pandemic, additional psychological care provided due to the COVID-19 outbreak, changes in ambulatory care, and changes in inpatient care due to the pandemic.

Approximately half of the centers naïve to the use of telemedicine before the pandemic provided remote visits during COVID-19, but this was less frequent than face-to-face visits. Thirteen centers reported equal or more telemedicine than face-to-face visits before December 2019. Only one of the five centers that did not change their ambulatory care model (Europe −1, South America −2, Asia/Middle East/Africa −2) used telemedicine before the pandemic.

The shift towards telemedicine was not consistent with the reimbursement of telemedicine, which was covered equally (n = 23, 33 %) or less compared to in-person visits (n = 20, 28.5 %) in two-thirds of all centers. Most (n = 23, 85.2 %) of the 27 centers for which telemedicine was not reimbursed provided it to their children with type 1 diabetes regardless of financial loss.

More centers provided additional psychological support due to the pandemic if telemedicine was reimbursed equally to in-person visits (additional care in 19 % vs. 14 % if less or no reimbursement and no additional psychological service in 14 % vs. 53 % (full vs. partial/no telemedicine reimbursement).

Almost all (n = 67, 96 %) centers were planning at least partially to continue to provide telemedicine. The remaining three centers used telemedicine partially or fully during the pandemic, although their healthcare systems did not refund the telemedicine visits equally to in-person visits.

3.3. Changes in pediatric diabetes care and outcomes of children with type 1 diabetes

The centers that did not change ambulatory care practices were grouped with those with a partial switch to telemedicine for the regression analysis due to their small number.

Overall, after adjusting for confounding factors (Section 2.2), the repeated measurements linear regression models showed that the changes in diabetes care during COVID-19 (offering or not additional psychological care $p = 0.011$, partial/strong switch to telemedicine or no change in ambulatory practice $p < 0.001$) were associated with fluctuations in glycemic control in the first and second year of the pandemic (Figs. 2A and 3A). The associations between different care practices and HbA1c, DKA, and SH were diverse. Interestingly, offering telemedicine before COVID-19 was significantly associated with the participant's outcomes (linear regression models for HbA1c and DKA – $p < 0.001$ and SH – $p = 0.028$). Specific differences between centers using or not telemedicine before the pandemic in the years 2018–2021 are shown in supplementary material Fig. S1 A–C.

3.3.1. Offering telemedicine before the pandemic

Centers that offered telemedicine care before the pandemic had lower HbA1c at all time points (2018 – 8.06 vs. 8.13 % (64.6 vs. 65.4 mmol/mol), 2019—8.07 vs. 8.14 % (64.7 vs. 65.5 mmol/mol), 2020 – 8.08 vs. 8.22 % (64.8 vs. 66.3 mmol/mol), 2021 – 8.06 vs. 8.11 % (64.6 vs. 65.1 mmol/mol), $p < 0.001$ for differences in years 2018 to 2020 and $p = 0.004$ for differences in 2021) compared to those that did not use telemedicine before December 2019. Changes in HbA1c in subsequent years were significantly associated with pre-pandemic use of telemedicine ($p < 0.001$). This change was more remarkable in centers naive to telemedicine before the pandemic, with a substantial increase in HbA1c in 2020 and a greater decrease in 2021.

There was a significant association between offering telemedicine before the pandemic and the changes in the proportion of children with type 1 diabetes with at least one DKA episode ($p < 0.001$). The proportion of individuals with DKA was significantly higher in centers offering telemedicine before the pandemic (12 % vs. 4 %, $p < 0.001$). Still, it decreased annually to reach in 2021 values similar to those from centers not offering telemedicine before the pandemic (1 % vs. 1 %, $p = 0.547$). The proportion of children with type 1 diabetes with DKA in centers not using telemedicine before COVID-19 varied, with an overall significant increase in 2021.

The proportion of children with type 1 diabetes with at least one SH episode was significantly lower in 2018 in centers offering telemedicine before the pandemic, and changes during the pandemic were also associated with telemedicine use before COVID-19 ($p = 0.028$). Details are included in the supplementary online material.

3.3.2. Additional psychological care offered due to COVID-19

The association between changes in HbA1c, the proportion of children with type 1 diabetes with at least 1 DKA episode, the proportion with at least one episode of SH, and additional psychological care are illustrated in Fig. 2 and the supplementary materials (Fig. S2 A). Linear and logistic regression models with repeated measurements revealed

Table 1
Cumulative and annual data through the 4-year observation period for all participating centers with respective p values for the overall change between 2018 and 2021. Data presented as (%) for binary variables and median [IQR] for continuous variables. N – number of documented individuals in SWEET. BMI SDS – Body mass index standard deviation score, SH – the proportion of individuals with at least 1 episode of severe hypoglycemia, DKA – the proportion of individuals with at least 1 episode of diabetic ketoacidosis, CGM – continuous glucose monitoring.

Variable	2018 N		2019 N		2020 N		2021 N		All N		p value for 2018–2021 overall
Age in years	26,853	13.8 [10.4–16.6]	28,108	13.9 [10.6–16.7]	27,297	14.0 [10.7–16.7]	27,978	14.0 [10.8–16.8]	42,978	14.8 [11.2–17.7]	<0.001
Age at diabetes onset in years	26,853	7.4 [4.2–10.7]	28,108	7.5 [4.2–10.7]	27,297	7.6 [4.3–10.8]	27,978	7.6 [4.3–10.8]	42,978	7.9 [4.5–11.2]	0.005
Diabetes duration in years	26,853	4.9 [2.4–8.2]	28,108	5.0 [2.5–8.3]	27,297	5.0 [2.5–8.3]	27,978	5.0 [2.4–8.5]	42,978	5.4 [2.7–8.9]	0.002
HbA1c %	26,064	7.8 [7.0–8.8]	27,396	7.7 [6.9–8.8]	25,273	7.7 [6.9–8.7]	26,018	7.6 [6.9–8.7]	39,579	7.7 [6.9–8.8]	<0.001
HbA1c mmol/mol	26,064	61 [53–73]	27,396	61 [52–73]	25,273	60 [52–72]	26,018	60 [52–71]	39,579	60 [52–73]	<0.001
BMI-SDS	25,170	0.55 [−0.13–1.27]	27,109	0.55 [−0.14–1.28]	24,631	0.59 [−0.11–1.31]	25,896	0.61 [−0.11–1.35]	39,341	0.57 [−0.15–1.32]	<0.001
Total daily insulin dose unit/kg	22,190	0.81 [0.65–0.99]	24,547	0.81 [0.65–0.98]	22,755	0.81 [0.64–0.99]	22,978	0.80 [0.63–0.98]	34,848	0.81 [0.64–1]	0.004
Percent male	26,853	(51.6)	28,108	(51.8)	27,297	(51.5)	27,978	(51.8)	42,978	(52.0)	0.858
SH	26,853	(1.9)	28,108	(1.8)	27,297	(1.8)	27,978	(1.6)	42,978	(1.7)	0.087
DKA	26,853	(1.4)	28,108	(1.4)	27,297	(1.2)	27,978	(1.4)	42,978	(1.4)	0.3
Insulin pump use %	26,853	(44.0)	28,108	(47.5)	27,297	(48.6)	27,978	(51.8)	42,978	(46.2)	<0.001
CGM use %	22,632	(48.4)	23,766	(58.7)	24,553	(64.9)	25,671	(70.7)	38,197	(60.5)	<0.001
Insulin pump/ CGM use %	26,853	(59.9)	28,108	(66.9)	27,297	(72.1)	27,978	(76.6)	42,978	(67.8)	<0.001
Number of datasets per individual	26,853	3 [2–4]	28,108	3 [2–4]	27,297	2 [1–3]	27,978	2 [1–4]	42,978	2 [1–3]	<0.001

that additional psychological care was significantly associated with changes in all glycemic outcomes (HbA1c – $p = 0.011$, DKA – $p < 0.001$, and SH – $p < 0.001$). The proportion of children with type 1 diabetes with at least one DKA or one SH was consistently lower in centers with additional psychological support than those without additional support. Conversely, an increase in HbA1c in those not offering additional psychological support and a decrease in centers with such support (respectively 8.06–8.12 % (64.6–65.2 mmol/mol) and 8.12–7.98 % (65.2–63.7 mmol/mol), $p < 0.001$ for both) were observed.

3.3.3. Changes in ambulatory care

Changes in ambulatory care were significantly associated with changes in HbA1c during the pandemic ($p < 0.001$). Centers that switched partially to telemedicine or did not change their ambulatory practices showed a steady increase in HbA1c during the four years of observation, while those that switched almost entirely to telemedicine demonstrated significantly improved HbA1c values in 2021 compared to 2018, despite a higher pre-pandemic HbA1c and an initial increase observed in 2020 (Fig. 3A.). Different approaches to ambulatory care during COVID-19 were not associated with a significant change in the proportion of children with type 1 diabetes with at least 1 DKA episode (Fig. 3B). Still, they were associated with the proportion of individuals with at least 1 SH episode ($p = 0.001$) (supplementary Fig. S2 B).

4. Discussion

Overall, the presented data showed that changes to the delivery of diabetes care due to the pandemic were associated with HbA1c as well as acute diabetes complications - not only immediately following the outbreak, reflecting substantial changes during lockdowns, but also in the following 2 years. These over-arching, international insights driven by the COVID-19 pandemic provided data for future developments in pediatric diabetes care.

In this 4-year observation period, glycemic control in centers that routinely adopted telemedicine improved, whereas moderate or no telemedicine visits were associated with increasing HbA1c. Contrary to a previous study showing increased rates of DKA [16] during the first wave in 2020, ambulatory practices did not seem to impact the proportion of children with type 1 diabetes with acute complications. Our 4-year, real-world, multinational study outcomes are consistent with single pediatric diabetes center reports demonstrating glycemic control improvement [13,18] or preservation [14,15] during the pandemic. Other authors associated their findings with increased technology usage [15,17,26]. However, we have shown that the association between change in ambulatory care practices and improvement in HbA1c was significant even after adjusting for treatment modality. This observation and previous evidence that diabetes technology use, especially CGM, independently positively impacts glycemic control [27,28] identify management approaches associated with improved glycemic outcomes. Unfortunately, worldwide disparities in access to modern technologies hamper their universal use and detrimentally influence the outcomes [29], particularly during the pandemic.

We also noted that pre-COVID-19 differences in HbA1c, DKA, and SH between centers offering telemedicine and those naive to telemedicine in 2018 decreased 2 years after the pandemic outbreak. As we adjusted for technology use, this improvement can be potentially accounted for by adopting new models of care and flexibility in introducing novelties in daily care, as demonstrated in adult populations with diabetes [30].

Additional psychological care showed an association with lower HbA1c, as well as with a lower proportion of DKA and SH events. Children with type 1 diabetes from centers that offered additional psychological support had lower HbA1c, less DKA, and SH before the pandemic as well as 2 years after the pandemic outbreak. Structured psychological support for young individuals with diabetes embedded into multidisciplinary care [31] offers measurable benefits beyond glycemic control [32]. Not only interventions but the general availability of psychological care in pediatric diabetes centers was shown to be associated with decreased rates of DKA [33]. Easy access may facilitate early referral, engagement with children and adolescents with deteriorating glycemic control, support in maintaining motivation, and timely diagnosis of mental health problems. The positive associations of additional psychological support offered by centers during the pandemic may suggest, that these diabetes teams tried to and had resources to provide more than just routine diabetes care in this extraordinary situation. Maybe this proactive attitude allowed the children, adolescents and their caregivers to focus more on glycemic control. Mental health specialists may have also support for other diabetes team members and help them better adjust the care and treatment to the individual needs of the family.

In some of the graphs, a diversion in 2020 from the general trend for the 4 years can be noted. This phenomenon may reflect the initial reaction to the requirement of an immediate change in daily routines. Alternatively, it may correspond to a reporting bias in the data gathered in the first months of the pandemic confounded by greater attendance or hospitalizations of those who had more diabetes-related complications, had an acute complication, or were strictly compliant with their visits and laboratory test schedule. This might suggest that the interpretation of data from the initial pandemic year should be taken with caution.

The limitations of a registry-based study and self-reporting apply to this study. It cannot be considered a population-based study as not all

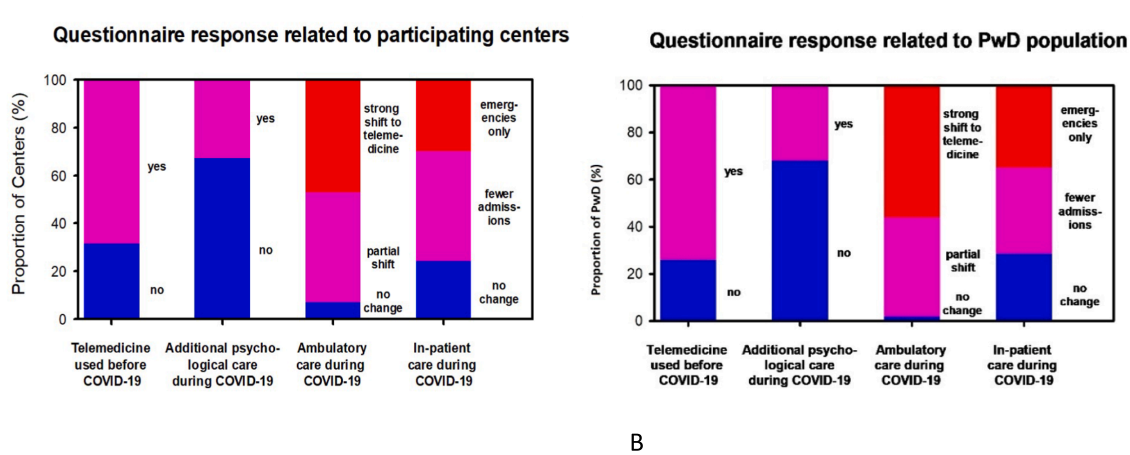

Fig. 1. Proportions of centers (A) and young people with type 1 diabetes (PwD) (B) treated in the centers in relation to the questionnaire responses regarding: telemedicine offered before the pandemic, additional psychological care offered due to COVID-19 outbreak, changes in ambulatory care and changes in in-patient care due to the pandemic.

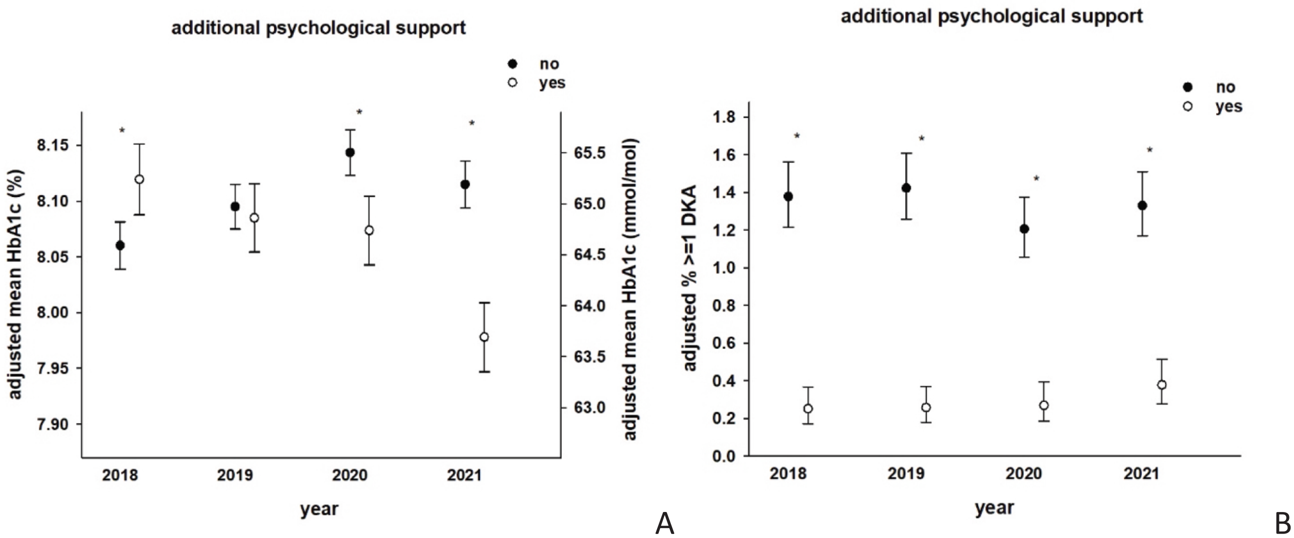

Fig. 2. The specific changes of HbA1c (A) and the proportion of children with type 1 diabetes with at least 1 DKA (B) regarding additional psychological care offered due to the pandemic; *$p < 0.05$.

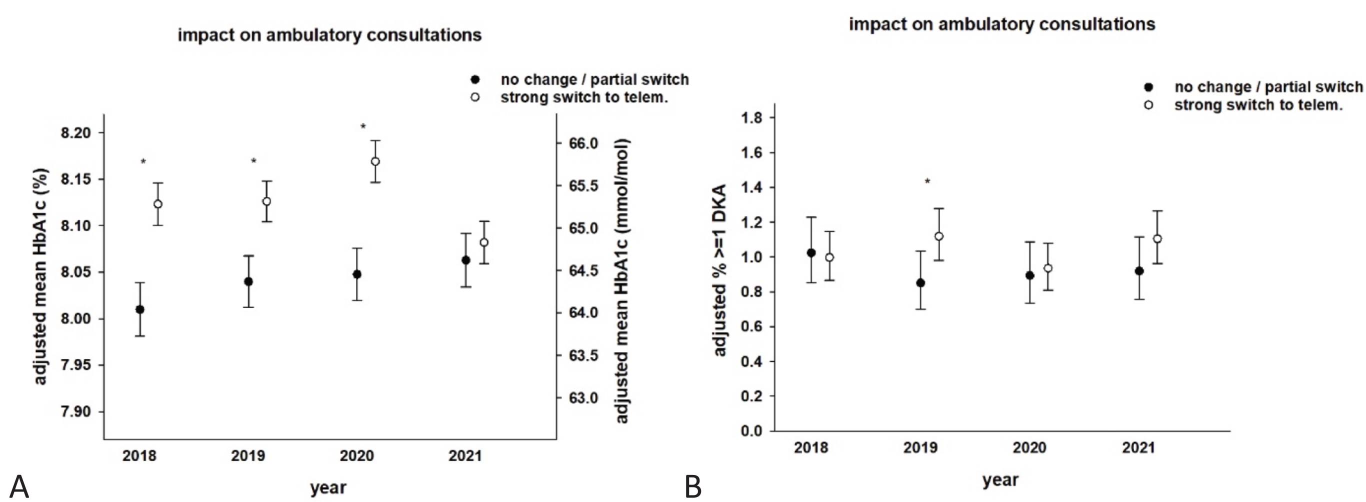

Fig. 3. The specific changes of HbA1c (A) and the proportion of children with type 1 diabetes with at least 1 DKA (B) regarding the adoption of telemedicine in ambulatory care due to the pandemic; *$p < 0.05$.

centers from each country participated in the international SWEET registry. Additionally, to provide a full 4-year dataset for analysis, the results were based on data from 72 % of the SWEET centers. The study was also limited by self-reporting and self-evaluation of changes in care, as there was no other tool to capture this information at that time. Several visits were potentially lost during the pandemic; however, our sensitivity analysis adjusted for the number of datasets sent to the SWEET database and did not impact the results. It cannot be excluded that teamwork and a more flexible approach to challenging situations contributed to these results [34] – these factors were not investigated in this study.

The strength of our study is the large multicentral, multinational, multicultural dataset, including 40,000 young people with type 1 diabetes from the well-structured and audited SWEET registry [35].

5. Summary

Changes in pediatric type 1 diabetes care driven by the COVID-19 pandemic and reported to the international SWEET registry showed significant associations with HbA1c and the proportion of children with type 1 diabetes who experienced at least 1 DKA or 1 SH throughout the first two years of the pandemic. The impact of the transformation of pediatric diabetes care delivery, including broader adoption of telemedicine and offering additional psychological care during the pandemic crisis, occurred independently of the concomitant increase in technology use. It may be that a hybrid diabetes care model with telemedicine may be adopted in routine diabetes care in the future and may also play a role in reducing disparities. However, diabetes clinics showed some hesitancy to maintain the use of telemedicine when reimbursements were inadequate, and therefore, a hybrid model could depend on sufficient reimbursement from payers.

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Author contributions

A.C. and K.D. designed the study. A. C. researched data, participated in data interpretation, and wrote the manuscript. S.L. helped design the study, performed the statistical analysis, participated in data interpretation, and reviewed and edited the manuscript. K.D. participated in data interpretation and reviewed and edited the manuscript. H.A., T.A., N.B., N.C., L.DS., D.M., B.S., C.S., M.C.T., and B.Z. contributed to the discussion, reviewed and edited the manuscript. All authors approved the final version of the manuscript. A.C., S.L., and K.D. are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: none reported. SWEET is a registered non-profit charity research collaboration in Hannover, Germany (NCT04427189).

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2023.110809.

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