Insulin Pump Utilization in 2017–2021 for More Than 22,000 Children and Adults With Type 1 Diabetes: A Multicenter Observational Study

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This large type 1 diabetes cohort study showed that insulin pump utilization has increased over time and that use differs by sex, insurance type, and race/ethnicity. Insulin pump use was associated with more optimal A1C, increased use of continuous glucose monitoring (CGM), and lower rates of diabetic ketoacidosis and severe hypoglycemia. People who used an insulin pump with CGM had lower rates of acute events than their counterparts who used an insulin pump without CGM. These findings highlight the need to improve access of diabetes technology through provider engagement, multidisciplinary approaches, and efforts to address health inequities.

Incidence rates of type 1 diabetes are increasing among children, particularly those in racial/ethnic minority groups (1,2). Registry studies have found that suboptimal glucose levels and adverse diabetes outcomes such as severe hypoglycemia and diabetic ketoacidosis (DKA) are common among many groups with type 1 diabetes (3,4). Although landmark studies have highlighted the importance of intensive diabetes management to reduce complications (5), other studies have shown that many children with type 1 diabetes do not have glucose levels in the target ranges recommended in national and international guidelines (6–8).

Optimal type 1 diabetes care often involves the use of various modalities of diabetes technology, and specifically insulin pumps and continuous glucose monitoring (CGM) systems. National studies have shown that the use of insulin pump therapy and CGM have increased over time (6,9). Previous data and trends show that effective use of diabetes technology can enhance diabetes care and improve long term outcomes in pediatric and adult populations. A 2010 Cochrane systematic review and multiregistry pediatric type 1 diabetes study found a significant difference in A1C among insulin pump users compared with injection therapy users (10–12). Furthermore, the SEARCH for Diabetes in Youth study, the T1D Exchange clinic registry, and other research has demonstrated lower A1C levels among insulin pump and CGM users compared with injection therapy users and nonusers of CGM (6,13–16). Similar findings have been seen reported in adult populations with type 1 diabetes (17,18).

Insulin pump users have decreased rates of DKA, fewer severe hypoglycemia events, and reduced hospital days (6,19–21). Although diabetes technology remains an asset to optimal care, there are persistent health inequities, with the SWEET and T1D Exchange registries showing varying insulin pump use among various global type 1 diabetes centers and within various racial/ethnic minority groups (6,22,23).

National quality improvement (QI) initiatives have focused on increasing utilization rates of diabetes technology because of the evidence of its benefits and

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reductions of adverse diabetes outcomes with its use (24,25). However, ongoing data on real-world use of diabetes technology across the life span, from the pediatric to older-adult populations with type 1 diabetes, remain limited. This observational study examined trends in insulin pump use compared with multiple daily injection (MDI) insulin regimens and CGM utilization trends, as well as A1C and rates of adverse diabetes outcomes among a large, multicenter collaborative type 1 diabetes cohort in the United States.

Research Design and Methods

The T1D Exchange Quality Improvement Collaborative (T1DX-QI) is a multicenter initiative comprising more than 40 data-sharing clinical centers throughout the United States. The aim of the Collaborative is to engage in information-sharing on clinical practices and data collection to identify and lead QI initiatives to improve evidence-based diabetes care delivery with the hope of positively affecting diabetes outcomes (26).

Insulin pump, MDI, and CGM users were identified through the T1DX-QI electronic medical records database. The database includes people with type 1 diabetes from multiple centers in the Collaborative. Inclusion criteria were a diagnosis of type 1 diabetes, age >2 years, and at least one A1C result and one clinic encounter between 2017 and 2021.

Quantitative data were reported as mean ± SD, and categorical data were represented as frequencies and percentages. *t* Tests were used to analyze continuous variables, and χ^2 tests were used to analyze categorical variables. Sex was identified as male or female. Insurance status was categorized as public, private, or other. Age was described as a categorical variable.DKA was defined as the presence of *1*) hyperglycemia, with blood glucose >11 mmol/L (>198 mg/dL), *2*) venous pH <7.3 or serum bicarbonate <15 mmol/L, and *3*) ketonuria and ketonemia. Severe hypoglycemia was defined as a hypoglycemia event requiring external assistance.

Results

Throughout the 5 years of data collection, there was an overall increase in insulin pump utilization from 59% in 2017 to 66% in 2021 (Figure 1).

General characteristics of the entire cohort in 2021 show that there were statistically significant differences in sex, insurance coverage and concurrent use of CGM between insulin pump and MDI regimen users. Diabetes technology use varied across age and race/ethnicity (Table 1). The insulin pump group was more likely to have female sex (*P* <0.001), to have private insurance (*P* < 0.001), and to use CGM. There were also differences in insulin pump and MDI use by race/ethnicity, as shown in Table 1 (*P* <0.001). When the use of insulin pump was compared with the use of an MDI regimen within racial/ethnic groups, insulin pump use was higher among non-Hispanic White (70 vs. 30%), as compared with non-Hispanic Black (41 vs. 59%) patients with type 1 diabetes (*P* <0.001), as shown in Supplementary Table S1.

Insulin pump users were found to have a lower mean A1C than MDI users across all years from 2017 to 2021, with the most recent 2021 data showing mean A1C among insulin pump users of 8.2 ± 1.8% compared with a mean A1C in MDI users of 8.4 ± 2% (*P* <0.001), as shown in Table 2. This lower A1C trend among insulin pump users persisted across all age-groups, as shown in Figure 2.

When CGM use was added, mean A1C levels in the group using an insulin pump with CGM were lower compared with those using an insulin pump without CGM (8.1 ± 1.7 vs. 8.6 ± 1.8%, *P* <0.001). Furthermore, DKA occurred in fewer patients using an insulin pump with CGM than in those using an insulin pump without CGM (556 [5%] vs. 322 [10%], *P* <0.001), as shown in Table 3. This trend of fewer DKA events was also seen among MDI users with versus without CGM (396 [8%] vs. 316 [11%], *P* <0.001), as shown in Table 4.

Discussion

Although there is evidence that the use of diabetes technology such as insulin pumps and CGM systems improves glucose levels and diabetes care, there remain limited data on the use of diabetes technology as it relates to outcomes in the real-world population with type 1 diabetes. The T1DX-QI initiatives have successfully increased the use of CGM and insulin pumps, depression screening, and access to care (27). This observational study tracked insulin pump use over time and highlights the relationship between the use of diabetes technology and diabetes outcomes such as A1C, DKA, and severe hypoglycemia in a large, multicenter, pediatric and adult collaborative cohort with type 1 diabetes.

The data show that rates of insulin pump use are increasing over time, but there seems to be an inequity in that the greatest use is among individuals who are

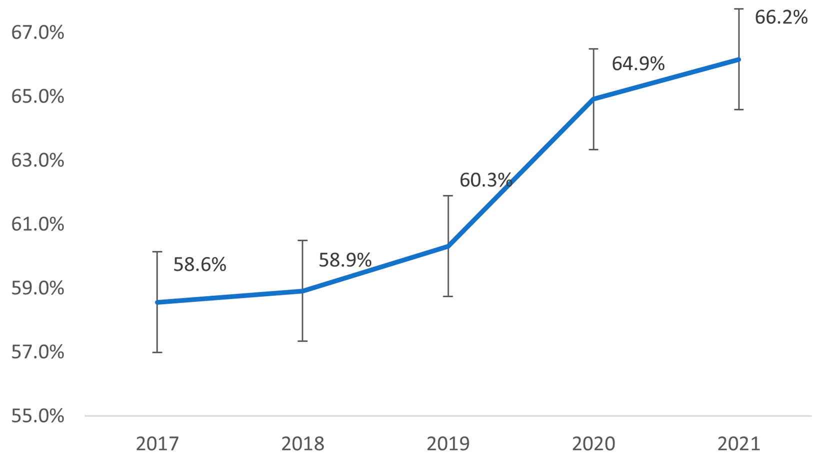

FIGURE 1 Insulin pump utilization rates, 2017–2021 (N = 14,867).

non-Hispanic White and those who have private insurance. This inequity appears consistent with health disparities that are known to exist among children with chronic conditions (28). Specifically, racial/ethnic disparities have been related to type 1 diabetes care, showing higher A1C levels, more varied engagement with daily diabetes care, more adverse diabetes outcomes, and lower diabetes technology utilization

TABLE 1 Patient Characteristics of Insulin Pump Versus MDI Regimen Users

	Insulin Pump Group n = 14,867	MDI Group N = 7,621	P
Age, years	19.8 ± 12.7	19.3 ± 13.5	0.03
Age group, years*			0.001
<6	331 (2)	299 (4)	<0.001
6–11	2,313 (16)	1,374 (18)	<0.001
12–17	5,682 (38)	2,878 (38)	0.5
18–24	3,952 (27)	1,892 (25)	0.005
25–50	1,827 (12)	692 (9)	<0.001
50–65	520 (3)	334 (4)	0.001
>65	242 (2)	152 (2)	0.05
Female sex	7,476 (50)	3,472 (46)	<0.001
Race/ethnicity*			<0.001
Non-Hispanic White	10,960 (74)	4,614 (61)	<0.001
Non-Hispanic Black	938 (6)	1,327 (17)	<0.001
Hispanic	1,105 (7)	682 (9)	<0.001
Other	1,864 (13)	998 (13)	0.2
Insurance*			<0.001
Public	3,699 (25)	2,513 (33)	<0.001
Private	7,935 (53)	2,826 (37)	<0.001
Other	3,233 (22)	2,282 (30)	<0.001
CGM user	11,695 (79)	3,630 (48)	<0.001
Most recent A1C, %	8.2 ± 1.8	8.5 ± 2.1	<0.001
Most recent A1C, mmol/mol	66.1 ± 18.1	69.4 ± 25.4	<0.001
DKA	878 (6)	712 (9)	<0.001
Severe hypoglycemia	256 (2)	252 (3)	<0.001

Data are mean ± SD or n (%). *Adjusted for Bonferroni-corrected P value.

TABLE 2 A1C (%) for Insulin Pump and MDI Regimen Users, 2017–2021 (N = 22,463)

Year	Insulin Pump Group	MDI Group	*P*
2017	8.4 ± 1.6	8.6 ± 1.9	<0.001
2018	8.6 ± 1.7	8.8 ± 1.9	<0.001
2019	8.4 ± 2.7	8.6 ± 2.4	<0.001
2020	8.4 ± 1.9	8.5 ± 2.1	<0.001
2021	8.2 ± 1.8	8.4 ± 2	<0.001

Data are mean ± SD.

among individuals in racial/ethnic minority groups (23,29–37).

Various barriers to the adoption of diabetes technology have been identified, including limited insurance access, cost, family preferences, and lack of comfort with technology (38–41). Studies have shown that having private insurance is associated with more optimal glycemic control as evidenced by A1C, increased diabetes technology access, and lower rates of diabetes-related complications (42–46).

Interestingly, some previous studies have shown that the use of diabetes technology has lessened the impact of varied socioeconomic and insurance factors as predictors of diabetes outcomes (42,47). This finding suggests that access to and use of diabetes technology may assist with narrowing disparities in glycemic control. Fortunately, diabetes technology is becoming increasingly more accessible for people with type 1 diabetes and public insurance, so more studies are needed to examine the relationships among insurance and socioeconomic status, method of insulin delivery, and diabetes outcomes.

It is also important to consider that unconscious and conscious bias among diabetes care providers can exist and affect the initiation of diabetes technology, ultimately adversely affecting long-term diabetes outcomes, and this bias offers an opportunity for intervention (48,49). Among diabetes care providers, increasing trainees' knowledge of and confidence in using diabetes technology can further increase access for patients (50). Novel approaches to addressing racial/ethnic disparities in diabetes technology use among established culturally sensitive diabetes initiatives are essential (51). The T1DX-QI has developed and undertaken initiatives to improve health inequities by proper data identification, measuring implicit bias from provider and institutional perspectives, and engaging community leaders and clinics in addressing these issues (52).

Evidence from previous research has shown that early adoption of insulin pump therapy in children (53,54) and access to hybrid closed-loop automated insulin delivery (AID) systems (55,56) improves diabetes outcomes, highlighting the need for tailored care incorporating diabetes technology. Furthermore, studies have shown that diabetes technology use is equally effective in older adults, with improved glycemic outcomes compared with the use of MDI regimens. However, anxiety around using diabetes technology in the setting of cognitive impairment can negatively affect the optimization of technology use in the older adult population (57–59).

One interesting finding of this study is that, although there was an increased number of insulin pump users versus MDI users in most age-groups, there was a relatively similar preference for insulin pump versus MDI therapy among the cohort who were 12–17 years of age. Recent studies have shown that a small proportion of

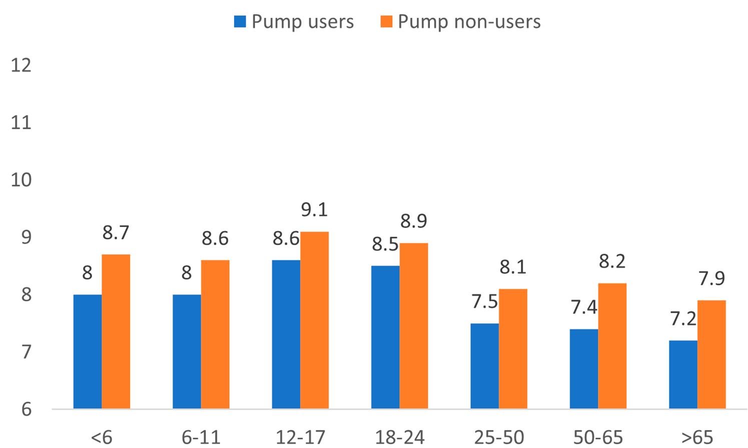

FIGURE 2 A1C among insulin pump users versus those using an MDI regimen across age-groups (N = 22,463).

TABLE 3 Subgroup Analysis to Examine Clinical Outcomes in Patients Using an Insulin Pump With (*n* = 11,695) and Without CGM (*n* = 3,172)

	Patients Using Insulin Pump With CGM	Patients Using Insulin Pump Without CGM	*P*
A1C, %	8.1 ± 1.7	8.6 ± 1.8	<0.001
A1C, mmol/mol	64.5 ± 17.4	70 ± 19.2	<0.001
Patients with DKA	556 (5)	322 (10)	<0.001
Patients with severe hypoglycemia	180 (2)	76 (2)	0.004

Data are mean ± SD or *n* (%).

adolescents with type 1 diabetes meet recommended glycemic goals, and this situation does not improve during the years of adolescence (6,60). Although insulin pump use and private insurance were associated with improved glycemic control in this and other studies, there is some evidence showing little improvement of glycemic control during the adolescent time period regardless of insulin delivery method or insurance type (60). The contributors to these outcomes can be multifactorial, including adolescents navigating increasing autonomy in diabetes care and diabetes self-management behaviors, uncertainty related to transitioning from pediatric to adult care, and parental involvement in insulin pump care. Thus, continued investigation is needed to understand diabetes management during this transitional life stage (61–63).

The use of technology for type 1 diabetes management can be increased through telemedicine (64–66). However, this solution may be limited because adoption of telemedicine remains dependent on technology and health literacy of both providers and patients/families, health care system support, and potentially affected by challenges in resource-limited settings (67).

TABLE 4 Subgroup Analysis to Examine Clinical Outcomes in Patients Using an MDI Regimen With (*n* = 4,825) and Without CGM (*n* = 2,796)

	Patients Using MDI With CGM	Patients Using MDI Without CGM	*P*
A1C, %	8.7 ± 2.1	9.2 ± 2.3	<0.001
A1C, mmol/mol	72 ± 23	77 ± 25	<0.001
Patients with DKA	396 (8)	316 (11)	<0.001
Patients with severe hypoglycemia	137 (3)	115 (4)	0.003

Data are mean ± SD or *n* (%).

For youth with type 1 diabetes, conflicts between parents and children regarding diabetes care can affect decisions regarding the choice of insulin delivery method (68), and coaching methods have been shown to aid in such decision-making (69). In addition, continued psychosocial assessments after the adoption of diabetes technology are crucial because technology use can have both positive and negative effects on diabetes management over time. For example, one study found that depression scores were similar in youth with new-onset diabetes and those initiating insulin pump therapy, suggesting the need not only for screening of those adjusting to a new diabetes diagnosis, but also for possible adjustment challenges in those with an established diabetes diagnosis. Furthermore, insulin pump therapy has been associated with improved quality of life and decreased diabetes burden for caregivers of individuals with type 1 diabetes (70,71). Continued development of unique interventional approaches will be needed to nurture relationships among patients, caregivers, and health care providers with regard to the adoption of diabetes technology.

Novel approaches have been shown to improve diabetes care in multidisciplinary and community settings, such as institutional programs that incorporate care coordination and behavioral therapy, interventions to improve pump management skills, and school-based programs to improve diabetes care in various settings. Promoting access to diabetes technology within these avenues is essential (72–74).

Conclusion

This article reports real-world data from a large cohort of children and adults with type 1 diabetes and shows that the use of an insulin pump with concurrent CGM can enhance diabetes care across many age-groups.

Limitations of this study include that the data were cross-sectional and that no causality could be established from these findings. Additionally, the use of newer diabetes technology devices such as the hybrid closed-loop AID systems, which can reduce hypoglycemia and increase time spent in the target glycemic range, was not included in this study. We anticipate that increased use of AID systems will further enhance diabetes care. Because the T1DX-QI is a multicenter initiative that primarily consists of clinics in academic settings in large, urban areas, future opportunities should include the involvement of diabetes centers or clinics in rural areas. This will allow investigation of a more diverse patient population to address health inequities and provide additional insights into various clinical practices.

Future work should also focus on various strategies to increase diabetes technology use. These include increasing provider education about technology adoption, encouraging youth and adults with type 1 diabetes to be early adopters of technology early in the course of their diabetes, addressing health inequities by data-sharing, providing focused bias training and psychological support, and increasing access to type 1 diabetes care via telemedicine.

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DUALITY OF INTEREST

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AUTHOR CONTRIBUTIONS

K.G wrote the first draft of the manuscript. O.E conceptualized the study. O.E., N.N., and S.R. analyzed the data. All authors reviewed and edited the manuscript. N.N. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

PRIOR PRESENTATION

A portion of the data included in this article was presented the American Diabetes Association's virtual 81st Scientific Sessions in June 2021.

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