BMJ Open Diabetes Research & Care

Enhancing equity in access to automated insulin delivery systems in an ethnically and socioeconomically diverse group of children with type 1 diabetes

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To cite: Pemberton J, Collins L, Drummond L, *et al*. Enhancing equity in access to automated insulin delivery systems in an ethnically and socioeconomically diverse group of children with type 1 diabetes. *BMJ Open Diab Res Care* 2024;**12**:e004045. doi:10.1136/bmjdrc-2024-004045

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjdrc-2024-004045).

Received 16 January 2024
Accepted 20 March 2024

Check for updates

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ABSTRACT

Introduction Manufacturer-supported didactic teaching programmes offer effective automated insulin delivery (AID) systems onboarding in children and young people (CYP) with type 1 diabetes (T1D). However, this approach has limited flexibility to accommodate the needs of families requiring additional support.

Research design and methods Evaluate the efficacy of an inperson manufacturer-supported didactic teaching programme (Group A), in comparison to a flexible flipped learning approach delivered virtually or inperson (Group B). Retrospective analysis of CYP with T1D using continuous glucose monitoring (CGM), who were initiated on AID systems between 2021 and 2023. Compare CGM metrics from baseline to 90 days for both groups A and B. Additionally, compare the two groups for change in CGM metrics over the 90-day period (Δ), patient demographics and onboarding time.

Results Group A consisted of 74 CYP (53% male) with median age of 13.9 years and Group B 91 CYP (54% male) with median age of 12.7 years. From baseline to 90 days, Group A lowered mean (±SD) time above range (TAR, >10.0 mmol/L) from 47.6% (±15.0) to 33.2% (±15.0) (p<0.001), increased time in range (TIR, 3.9–10.0 mmol/L) from 50.4% (±14.0) to 64.7% (±10.2) (p<0.001). From baseline to 90 days, Group B lowered TAR from 51.3% (±15.1) to 34.5% (±11.3) (p<0.001) and increased TIR from 46.5% (±14.5) to 63.7% (±11.0) (p<0.001). There was no difference from baseline to 90 days for time below range (TBR, <3.9 mmol/L) for Group A and Group B. Δ TAR, TIR and TBR for both groups were comparable. Group B consisted of CYP with higher socioeconomic deprivation, greater ethnic diversity and lower carer education achievement (p<0.05). The majority of Group B (n=79, 87%) chose virtual flipped learning, halving diabetes educator time and increasing onboarding cadence by fivefold.

Conclusions A flexible virtual flipped learning programme increases onboarding cadence and capacity to offer equitable AID system onboarding.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Automated insulin delivery (AID) systems have been recognized for enhancing glucose management in children and young people (CYP) with type 1 diabetes.
⇒ The positive impact of these systems has led to a technology appraisal in the UK, granting all CYP access to AID therapy.
⇒ This decision, however, introduces a significant challenge for the National Health Service in terms of efficiently managing the large-scale onboarding.

WHAT THIS STUDY ADDS

⇒ We demonstrate that implementing a flexible flipped learning onboarding programme, offering a choice between virtual and inperson sessions, can halve the time required by educators.
⇒ This approach enhances the onboarding cadence by fivefold and broadens the reach of AID therapy to a more diverse and deprived population.
⇒ Most importantly, the efficiency gain is achieved without compromising the effectiveness of the treatment, as evidenced by the comparable improvements in time in range (3.9–10.0 mmol/L) from around 50% to 64%.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The National Institute for Health and Care Excellence technology appraisal emphasizes the need for evidence-based programmes that are adaptable to the challenges of onboarding.
⇒ This real-world study offers a model that aligns with these requirements, providing a comprehensive set of resources and guidelines for implementation.
⇒ This approach could be instrumental in informing clinical practices and influencing policies aimed at enhancing equitable AID system onboarding.

INTRODUCTION

Type 1 diabetes (T1D) is a lifelong condition, marked by an autoimmune mediated deficiency in insulin production.[1] This presents an ongoing challenge for children and young people (CYP) with T1D to adjust their exogenous insulin administration to maintain a glycated hemoglobin (HbA1c) level below 48 mmol/mol.[2] For CYP who have access

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to advanced technologies, continuous glucose monitoring (CGM) has enabled the evaluation of glycemic control beyond HbA1c by using time in range (TIR, 3.9–10.0 mmol/L) with the target being 70%.[2 3] The advantage of CGM over self-monitoring of blood glucose for individuals with T1D is a modest increase of 5% in TIR (3.9–10.0 mmol/L),[4] with CYP from ethnically diverse and socioeconomically deprived backgrounds achieving a TIR between 50% and 60%.[5 6] CYP who do not meet a TIR of 70% is not unexpected, considering the daily variability in insulin requirements,[7] unpredictable eating and activity patterns,[8] and adolescents struggling with the daily diabetes self-management responsibilities.[8]

The advancement in technology with automated insulin delivery (AID) systems has enhanced T1D management further which is attributed to the adjustment of insulin delivery every 5–12 min driven by an algorithm using CGM values.[9] A systematic review reported an increase in TIR to approximately 70% in AID system users alongside improvements in quality of life,[10] which has been replicated in real-world studies.[11–14] A meta-analysis of randomised control trials of CYP with T1D using AID systems (ranging from 3 days to 6 months) reported relative increase from baseline of 11% for TIR, a 12% reduction in time above range (TAR, >10.0 mmol/L), and a 0.6% reduction in time below range (TBR, <3.9 mmol/L).[15] In a UK national pilot study, CYP with T1D from eight different centers (n=251) were onboarded to AID systems using varying manufacturer-supported and inhouse teaching programmes.[14] The cohort showed an increase in TIR from 49% to 65% at 3 months.[14] Consequently, the National Institute for Health and Care Excellence (NICE) extended the eligibility to all CYP with T1D nationally[16] which makes 29 000 CYP eligible for an AID system.[16]

The current infrastructure within UK diabetes teams to meet this challenge has led to some concerns on implementation. The absence of a nationally approved structured education programme[16] and the slow implementation of continuous subcutaneous insulin infusion (CSII) technology appraisal[17] since 2008 are worrying precedents.[18] The national paediatric pilot predominantly involved participants from a white ethnic background and lacked information on socioeconomic status (SES) or the need for interpreters.[14] Hence, the efficacy of this approach in a socioeconomically deprived and largely ethnic minority cohort remains unknown.

Within our center caseload, we support an ethnically diverse and socioeconomically deprived cohort that has had access to CGM systems since 2019.[19] In 2021, we started using a traditional didactic teaching approach using resources and personnel from the manufacturer to onboard AID users. We use all commercially available AID systems which include the MiniMed 780G System (780G), CamAPS FX (CAMS), t:slim X2 with Control IQ (CIQ), and the Omnipod 5 System (OP5). However, we faced challenges in acquiring sufficient and timely support for the increasing number of one-on-one training sessions required for families needing interpreters. Given our previous experience of suboptimal glycemic control in families requiring interpreter support[20] it was crucial to address this barrier. In light of the National Health Service England's (NHSE's) 'Core20PLUS5' programme to tackle health inequities[21] and international data attributing disparities in glucose control to unequal access to advanced diabetes technologies[22] a flexible programme was created to enhance equitable AID onboarding.

Flipped learning involving self-education, competency checks and subsequent reinforcement has been shown to be superior to didactic teaching methods for people living with long-term health conditions.[23 24] We have successfully implemented this model in our CGM academy.[6] Inspired by this, we developed a similar virtual flipped learning programme catering for each AID system and evaluated its efficacy.

Aims

1. Compare the clinical effectiveness of AID system onboarding using the manufacturer-supported didactic teaching programme (Group A) from baseline to 90 days after initiation.
2. Compare the clinical effectiveness of AID system onboarding using the flexible virtual flipped learning programme (Group B) from baseline to 90 days after initiation.
3. Compare the demographics between Group A and Group B and the change in glucose metrics (Δ) over 90 days of AID system use.
4. Compare the onboarding times and associated costs between groups.

RESEARCH DESIGN AND METHODS

Study design

We conducted a retrospective analysis of data sourced from CYP with T1D who were initiated on an AID system at Birmingham Women's and Children's NHS Foundation Trust between April 2021 to September 2023.

Study population and clinic characteristics

CYP diagnosed with T1D who initiated the use of an AID system. Within our center, 60% of the cohort comes from the most deprived socioeconomic quintile, and over 60% belong to ethnic minority groups,[25] which is in contrast to national demographics. Nationally, 76% are from white backgrounds with only 24% in the most deprived quintile.[25] We provide care for around 300 CYP with T1D supported by an equivalent full-time staff comprising two consultant diabetologists, five paediatric diabetes nurses, two paediatric diabetes dietitians, one social worker, one family support/youth worker, and one psychologist.

Inclusion criteria

1. CYP who have tested positive for at least one T1D autoantibody.
2. Completion of the validated CGM Academy Programme.[5 6]

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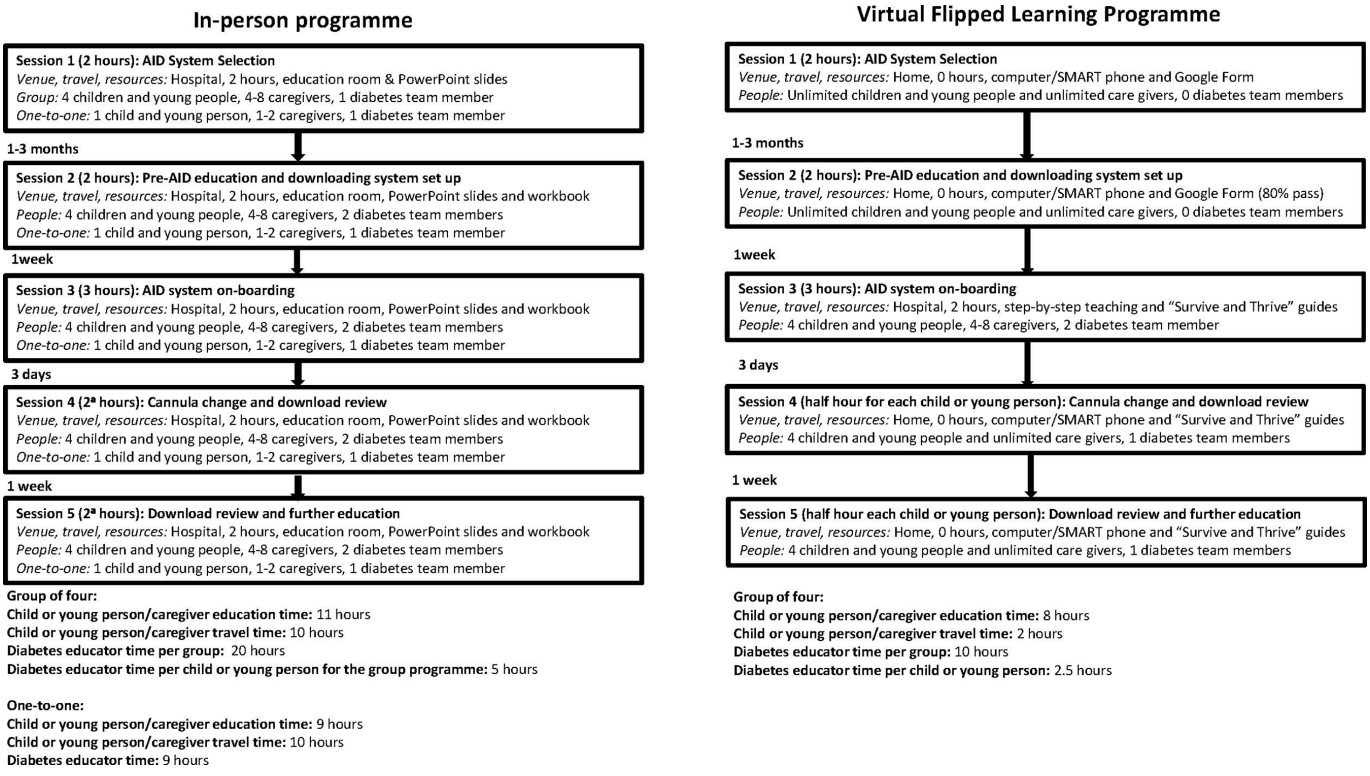

Figure 1 The structure, programme details and time requirements for the inperson programme and the virtual flipped learning programme. [a]1 hour for one-to-one sessions. AID, automated insulin delivery.

Exclusion criteria

1. Less than 6 months of CGM usage prior to commencing an AID system.
2. A minimum CGM data capture rate of 50% during both the 90-day period[26] prior to establishing the baseline and the subsequent 90-day data collection phase.

AID teaching programmes

Manufacturer-supported didactic teaching programme (Group A)—April 2021 to March 2023

This programme consists of five in-person sessions, structured to guide CYP through the process of AID system selection and use. The sessions are delivered in groups of four unless individuals need one-to-one sessions for language or educational challenges. The sequence begins with an AID system selection showcase, where the diabetes team displays the available AID systems, highlighting their respective pros and cons through a PowerPoint presentation. Following this, CYP choose their preferred AID system and are placed on a waiting list. The education programme starts with a pre-AID session that is followed by an onboarding session and two review sessions (figure 1). Manufacturer representatives support the pre-AID and onboarding sessions which are scheduled based on the representative's availability.

The educational materials for these sessions primarily include PowerPoint presentations and a range of resources from the manufacturers, such as Quick Start guides, 'Information For Use' manuals, and guides on basic AID system management and optimization techniques. Additionally, a historical generic insulin pump workbook created by our diabetes team is used, which covers infusion site management and provides essential contact information.

Virtual flipped learning programme (Group B)—April 2023 to October 2023

To address the difficulties encountered with the traditional approach, in November 2022, we launched a quality improvement initiative aimed at achieving self-sufficiency in AID system onboarding. From November 2022 to March 2023, our team emulated the development process previously established for our CGM Academy structured education programme, as detailed in existing literature.[5 6] This involved integrating the International Society for Pediatric and Adolescent Diabetes guidelines[27] and the American Association of Diabetes Educators standards[28] into our educational framework. We developed step-by-step teaching guides for team members, 'Survive and Thrive' guides for the CYP and their families, an AID starting setting calculator, a download assessment clinic tool, and Google Forms. The content of these resources was taken from the Advanced Technologies and Treatments for Diabetes (ATTD) consensus on AID technologies[29] and the UK's Diabetes Technology Network Best Practice Guidelines.[30] The resources were examined and verified by the device manufacturer's education team to ensure their accuracy and safety. We estimate it has taken 200 hours to create the virtual flipped learning programme and associated resources that are discussed in greater detail with download links in the online supplemental materials.

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Table 1 Group A (manufacturer-supported didactic teaching programme) versus Group B (flexible virtual flipped learning programme): Patient demographics and baseline CGM data

Characteristic		Group A (n=74)	Group B (n=91)	P value
Gender				0.884
Male	n (%)	39 (53%)	49 (54%)	
Female	n (%)	35 (47%)	42 (46%)	
Age (years)	Median (IQR: 25th, 75th)	13.8 (11.8, 15.0)	12.7 (9.9, 15.6)	0.772
Duration of diabetes (years)	Median (IQR: 25th, 75th)	7.4 (4.1, 10.0)	4.8 (2.6, 8.5)	**0.011**
Interpreter required				0.347
Yes	n (%)	5 (7%)	10 (11%)	
No	n (%)	69 (93%)	81 (89%)	
Therapy type				**0.004**
MDI	n (%)	42 (57%)	31 (34%)	
CSII	n (%)	32 (43%)	60 (66%)	
Socioeconomic status				
Index of Multiple Deprivation	Median (IQR: 25th, 75th)	7460 (2873, 15 732)	4437 (1612, 12 871)	**0.027**
Ethnic Group				**0.044**
White	n (%)	41 (56%)	34 (45%)	
Asian	n (%)	25 (34%)	30 (34%)	
Black	n (%)	6 (8%)	19 (21%)	
Mixed	n (%)	1 (1%)	4 (5%)	
Other	n (%)	1 (1%)	4 (5%)	
Main carer education				**0.004**
No qualification	n (%)	14 (19%)	20 (22%)	
1–4 GCSE grades A–C or level 4	n (%)	11 (15%)	22 (24%)	
≥5 GCSE grades A–C or level 4	n (%)	22 (30%)	8 (9%)	
≥2 A levels or equivalent	n (%)	8 (11%)	8 (9%)	
University degree or equivalent	n (%)	19 (25%)	27 (30%)	
Other (unknown qualification)	n (%)	0 (%)	6 (7%)	
AID system selected				**<0.001**
780G	n (%)	5 (7%)	10 (11%)	
CAMS	n (%)	7 (10%)	0 (0%)	
CIQ	n (%)	62 (84%)	9 (10%)	
OP5	n (%)	0 (0%)	72 (79%)	
Baseline glucose metrics				
GMI (mmol/mol)	Median (IQR: 25th, 75th)	59.8 (56.4, 66.5)	62.1 (58.8, 70.1)	0.052
MBG (mmol/L)	Median (IQR: 25th, 75th)	10.0 (9.3, 11.4)	10.5 (9.8, 12.2)	0.052
Baseline CGM metrics				
TBR2%: <3.0 mmol/L	Median (IQR: 25th, 75th)	0.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.609
TBR%: <3.9 mmol/L	Median (IQR: 25th, 75th)	1.0 (1.0, 3.0)	2.0 (1.0, 3.0)	0.558
TITR%: 3.9–7.8 mmol/L	Mean (±SD)	30.3 (±11.2)	28.0 (±11.0)	0.178
TIR%: 3.9–10.0 mmol/L	Mean (±SD)	50.4 (±14.0)	46.5 (±14.5)	0.078
TAR%: >10.0 mmol/L	Mean (±SD)	47.6 (±15.0)	51.3 (±15.1)	0.110
TAR2%: >13.9 mmol/L	Median (IQR: 25th, 75th)	19.0 (10.0, 29.0)	22.0 (15.0, 36.0)	**0.049**
Co-efficient of variation (%)	Median (IQR: 25th, 75th)	38.6 (35.7, 43.2)	39.8 (36.9, 43.3)	0.145
CGM usage				
CGM usage (months)	Median (IQR: 25th, 75th)	9 (7, 10)	18 (12, 24)	**<0.001**

Continued

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Table 1 Continued

Characteristic		Group A (n=74)	Group B (n=91)	P value
Per cent sensor use (%)	Median (IQR: 25th, 75th)	89.9 (74.8, 96.3)	87.0 (65.0, 96.3)	0.658[b]

Normally distributed data are presented as mean (±SD) and non-normally distributed data as median (IQR 25th, 75th).
AID, automated Insulin delivery; CAMS, CamAPS Fx; CGM, continuous glucose monitoring; CIQ, t:slim X2 with Control IQ (CIQ); CSII, continuous subcutaneous insulin infusion; 780G, MiniMed 780G System; GCSE, General Certificate of Secondary Education; GMI, glucose management indicator; MBG, mean blood glucose; MDI, multiple daily injections; OP5, Omnipod 5 System; TAR2, time above range level 2; TAR, time above range; TBR, time below range; TBR2, time below range level 2; TIR, time in range; TITR, time in tight range.

CYP and their families who were referred for AID therapy were sent a Google Form which allowed them to choose their preferred method of education: either inperson using the updated traditional programme (now without manufacturer support and with new materials) or through the new virtual flipped learning approach. CYP and families requiring an interpreter were invited to attend the inperson programme.

If the virtual flipped learning option was selected, the CYP then completed their device selection using the same Google Form. Following this, the CYP and/or their families undertook preinitiation education at home, employing a flipped learning model. The pre-AID flipped learning education involved completing a Google Form, which required participants to watch short videos and then answer a series of multiple choice questions. To successfully pass this stage and proceed to the onboarding session, participants were required to achieve a minimum score of 80%. The onboarding session remained inperson, where the flipped learning was reinforced using the 'Survive and Thrive' guides, while the two review sessions were conducted virtually via Microsoft Teams, already licensed by the Hospital Trust. All digital software packages received approval from the Hospital Trusts' Clinical Governance Team.

The structure and session details of both programmes, including the required education and travel time are depicted in figure 1.

Data collection

Demographic data

We extracted demographic details and clinical characteristics including age, gender, height, weight, duration of diabetes, UK Census ethnicity category (white, Asian, black, mixed, other),[31] need for an interpreter, type of therapy (baseline: multiple daily injections or CSII; AID system: 780G, CAMS, CIQ, and OP5), months using CGM, and postcode from the TWINKLE online diabetes management database. Using postcodes, we computed an Index of Multiple Deprivation (IMD) for each CYP to deduce their SES.[32] The English Indices of Deprivation is based on 37 distinct indicators across seven domains,

Table 2 Group A (manufacturer-supported didactic teaching programme) versus Group B (flexible virtual flipped learning programme): 90-day AID system data

		Group A (n=74)	Group B (n=91)	P value
90-day AID glucose metrics				
GMI (mmol/mol)	Median (IQR: 25th, 75th)	55.1 (52.7, 57.9)	56.0 (52.7, 58.8)	0.273
MBG (mmol/L)	Median (IQR: 25th, 75th)	9.0 (8.5, 9.6)	9.2 (8.5, 9.8)	0.273
90-day AID CGM metrics				
TBR2%: <3.0 mmol/L	Median (IQR: 25th, 75th)	0.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.083
TBR%: <3.9 mmol/L	Median (IQR: 25th, 75th)	2.0 (1.0, 3.0)	1.0 (1.0, 2.0)	0.540
TITR%: 3.9–7.8 mmol/L	Mean (±SD)	42.1 (±10.1)	43.7 (±9.8)	0.304
TIR%: 3.9–10.0 mmol/L	Mean (±SD)	64.7 (±10.2)	63.7 (±11.0)	0.536
TAR%: >10.0 mmol/L	Mean (±SD)	33.2 (±10.3)	34.5 (±11.3)	0.427
TAR2%: >13.9 mmol/L	Median (IQR: 25th, 75th)	9.5 (6.0, 14.3)	11.0 (7.0, 17.0)	0.266
Coefficient of Variation (%)	Median (IQR: 25th, 75th)	37.6 (34.3, 41.4)	39.6 (36.5, 43.2)	**0.015**
System usage				
Per cent sensor use (%)	Median (IQR: 25th, 75th)	96.5 (95.0, 98.0)	97.0 (95.0, 98.0)	0.957
AID automode (%)	Median (IQR: 25th, 75th)	95.5 (95.0, 97.0)	95.0 (91.0, 97.0)	0.943

Normally distributed data is presented as mean (±SD) and non-normally distributed data as median (IQR 25th, 75th).
AID, automated insulin delivery; CGM, continuous glucose monitoring; GMI, glucose management indicator; MBG, mean blood glucose; TAR2, time above range level 2; TAR, time above range; TBR, time below range; TBR2, time below range level 2; TIR, time in range; TITR, time in tight range.

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Table 3 Group A (manufacturer-supported didactic teaching programme) versus Group B (flexible virtual flipped learning programme): Δ from baseline to 90-day AID system usage

		Group A (n=74) Δ from baseline to 90-day AID system therapy	P value	Group B (n=91) Δ from baseline to 90-day AID system therapy	P value	Δ between the Δs of Groups A and B baseline to 90-day AID system therapy	P value
Glucose metrics							
GMI (mmol/mol)	Median (95% CI)	−5.4 (−7.1 to −4.0)	**<0.001**	−6.8 (−8.3 to −5.4)	**<0.001**	1.4 (−0.5 to 3.3)	0.135
MBG (mmol/L)	Median (95% CI)	−1.2 (−1.5 to −0.9)	**<0.001**	−1.5 (−1.8 to −1.2)	**<0.001**	0.3 (−1.0 to 0.7)	0.135
CGM metrics							
TBR2%: <3.0 mmol/L	Median (95% CI)	0.0 (0.0 to 0.0)	0.582	0.0 (0.0 to 0.0)	0.247	0.0 (0.0 to 0.0)	0.234
TBR%: <3.9 mmol/L	Median (95% CI)	0.0 (−0.5 to 0.5)	0.785	0.0 (−0.5 to 0.0)	0.104	0.0 (0.0 to 1.0)	0.380
TITR%: 3.9–7.8 mmol/L	Mean (95% CI)	11.7 (8.9 to 14.5)	**<0.001**	15.7 (13.9 to 17.5)	**<0.001**	−4.0 (−7.1 to −0.8)	**0.016**
TIR%: 3.9–10.0 mmol/L		14.3 (11.3 to 17.3)	**<0.001**	17.2 (15.0 to 19.4)	**<0.001**	−2.9 (−6.5 to 0.7)	0.114
TAR%: >10.0 mmol/L	Mean (95% CI)	−14.4 (−17.5 to −11.2)	**<0.001**	−16.8 (−19.2 to −14.4)	**<0.001**	2.4 (−1.4 to 6.3)	0.213
TAR2%: >13.9 mmol/L	Median (95% CI)	−8.0 (−11.5 to −6.0)	**<0.001**	−11.0 (−13.0 to −8.5)	**<0.001**	3.0 (−1.0 to 0.6)	0.112
Coefficient of variation (%)	Median (95% CI)	−1.1 (−2.3 to 0.2)	0.117	−0.7 (−1.8 to 0.5)	0.274	−0.4 (−2.0 to 1.3)	0.623

AID, automated insulin delivery; CGM, continuous glucose monitoring; GMI, glucose management indicator; MBG, mean blood glucose; TAR2, time above range level 2; TAR, time above range; TBR, time below range; TBR2, time below range level 2; TIR, time in range; TITR, time in tight range.

with the IMD scale ranging from 1 (most deprived) to 32 844 (least deprived).[32] To determine educational support required, we collected the primary carer's educational background according to UK Census benchmarks:[31] 0=no qualification, 1=1–4 General Certificate of Secondary Education (GCSE) grades A–C or level 4; 2 = ≥5 GCSE grades A–C or level 4; 3 = ≥2 A levels or equivalent; 4=university degree or equivalent; 5=other (unknown qualification).

Glucose metrics

Baseline data: CGM data were sourced from Dexcom Clarity, reflecting the 90 days preceding AID system initiation. The ATTD metrics were used for the CGM data analysis,[3] expressed as percentages, included TBR level 2 (TBR2, <3.0 mmol/L), TBR (<3.9 mmol/L), time in tight range (TITR, 3.9–7.8 mmol/L), TIR (3.9–10.0 mmol/L), TAR (>10.0 mmol/L), TAR level 2 (TAR2, >13.9 mmol/L), coefficient of variations (COV), and per cent sensor use. Absolute values reported were mean blood glucose (MBG). The glucose management indicator (GMI) represents the predicted HbA1c from CGM MBG using a regression equation model primarily derived from a white European population: GMI (mmol/mol) = 12.71 + 4.70587× MBG (mmol/L).[33] This equation was employed to compute GMI for each CYP. HbA1c results were not consistently available for CYP at 90 days due to a mismatch with the clinic appointments which are offered quarterly.

90-day data: 90 days after AID system initiation, CGM data previously discussed (90 days) and Automode percentage were sourced from where the AID system had been uploaded, which included Diasend (CAMS, CIQ), Glooko (CAMS, CIQ, OP5) and CareLink (780G).

Education and travel time calculations

The duration for the inperson sessions and Diabetes Educator led virtual sessions are predetermined and reflect the average completion time. Feedback from CYP and their families indicated an estimated round-trip travel time of 2 hours for each hospital session. Additionally, the two virtual flipped learning sessions that are self-paced take an estimated 2 hours to complete each, as per the feedback from CYP and their families. Figure 1 provides a detailed breakdown of the total estimated session and travel times.

Costings

The development and delivery of the virtual programme were calculated using National Health Service hourly rates, which vary by banding.[34] A Band 7 specialist diabetes dietitian (JP) created all the resources at a cost

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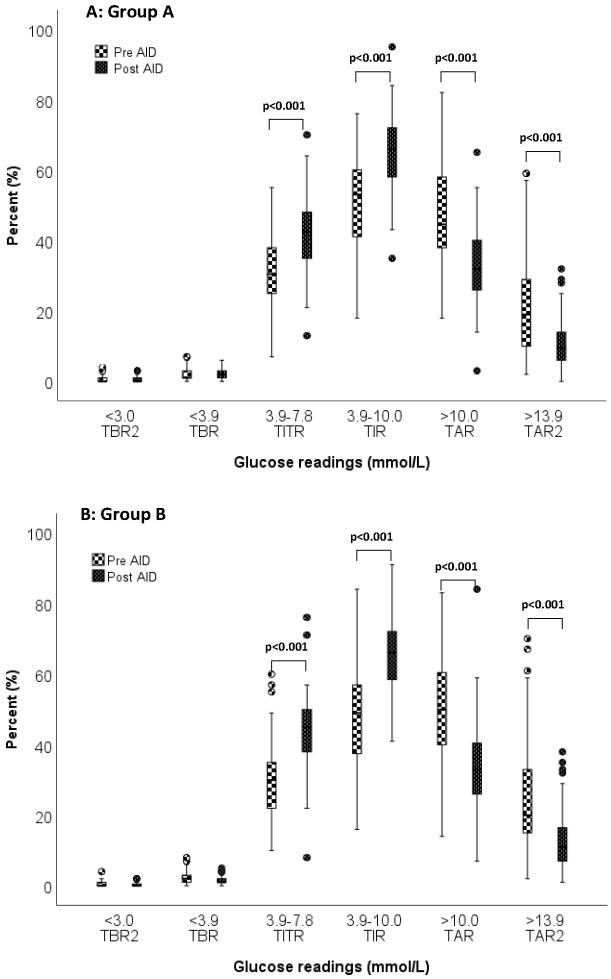

Figure 2 (A) Group A (manufacturer-supported didactic teaching programme) change from baseline to 90 days after AID onboarding. (B) Group B (flexible virtual flipped learning programme) change from baseline to 90 days after AID onboarding. AID, automated insulin delivery; TBR2, time below range level 2; TBR, time below range; TITR, time in tight range; TIR, time in range; TAR, time above range; TAR2, time above range level 2.

of £23 per hour. The education sessions were conducted by either a Band 6 or Band 7 specialist diabetes dietitian or a paediatric diabetes nurse, with the cost approximately £21 per hour.

Data analysis

All statistical analyses were executed using SPSS V.29.0. A value of p<0.05 was deemed statistically significant. Descriptive statistics are presented as means and ±SDs for normally distributed continuous parameters, median and IQR for non-normally distributed continuous variables and frequencies with percentages for categorical variables. Statistics describing the difference (Δ) from baseline to 90 days after AID system initiation for within group comparisons are reported as mean or median (Hodges-Lehman estimate) with 95% CIs. Paired t-tests were used for within-group comparisons and independent t-tests for comparisons between groups for parametric variables. Wilcoxon signed-rank tests were used for comparisons within groups and Mann-Whitney U tests for between-group comparisons for non-parametric variables.

RESULTS

A total of 171 CYP were onboarded on an AID system. Six CYP were excluded (four CYP had <6 months of CGM usage and two had <50% CGM data capture at baseline).

Comparing the clinical effectiveness of Group A and Group B

Manufacturer-supported didactic teaching programme (Group A)

Group A consisted of 74 CYP (53% male) with a median age of 13.9 years (IQR: 11.8, 15.0) and T1D duration of 7.4 years (IQR: 4.1, 10.0). The majority (56%) of the CYP in this cohort were from a white ethnic background, with 34% from an Asian heritage, with low percentages of CYP from black (8%), mixed (1%), and other (1%) ethnic backgrounds. Group A commenced on AID systems with a GMI of 59.8 mmol/mol (IQR: 56.4, 66.5), an MBG of 10.0 mmol/L (IQR: 9.3, 11.4), a TBR of 0.0% (IQR: 0.0, 1.0), a mean TITR of 30.3% (SD: ±11.2), a TIR of 50.4% (SD: ±9.0), a TAR of 47.6% (SD: ±15.0), and a TAR2 of 19.0% (IQR: 10.0, 29.0) (table 1). After 90 days of AID system usage, the GMI decreased to 55.1 mmol/mol (IQR: 52.7, 57.9) (table 2), an estimated median (95% CI) reduction of 5.4 mmol/mol (95% CI 7.1 to 4.0, p<0.001) (table 3). The MBG decreased to 9.0 mmol/L (IQR: 8.5, 9.6) (table 2), an estimated median reduction of 1.2 mmol/L (95% CI 1.5 to 0.9, p<0.001) (table 3). The TAR lowered to 33.2% (SD: ±10.3) (table 2 and figure 2A), a drop of 14.4% (95% CI 17.6% to 11.2%, p<0.001) (table 3). The TAR2 reduced to 9.5% (IQR: 6.0, 14.3) (table 2 and figure 2A), an estimated median drop of 8.0% (95% CI 11.5% to 6.0%, p<0.001) (table 3). The TITR increased to 42.1% (SD: ±10.1) (table 2 and figure 2A), an improvement of 11.7% (95% CI 8.9% to 14.5%, p<0.001) (table 3). The TIR increased to 64.7% (SD: ±10.2) (table 2 and figure 2A), an improvement of 14.3% (95% CI 11.3% to 17.3%, p<0.001) (table 3). No changes were observed for TBR2, TBR and COV as detailed in tables 1–3.

Flexible virtual flipped learning programme (Group B)

Group B included 91 CYP (54% male) with a median age of 12.7 years (IQR: 9.9, 15.6) and T1D duration of 4.8 years (IQR: 2.6, 8.5). The majority (55%) of the CYP in Group B were from minority ethnic groups (Asian=34%, black=21%, mixed=5%, other=5%) with 45% of the CYP having a white ethnic background. Group B started the AID systems with a GMI of 62.1 mmol/mol (IQR: 58.8, 70.1), an MBG of 10.5 mmol/L (IQR: 9.8, 12.2), a TBR of 0.0% (IQR: 0.0, 1.0), a TITR of 28.0% (SD: ±11.0), a TIR of 46.5% (SD: ±14.5), a TAR of 51.3% (SD: ±15.1), and a TAR2 of 22.0% (SD: 15.0, 36.0) (table 1). After 90 days on their AID systems, the GMI decreased to 56.0 mmol/mol (IQR: 52.7, 58.8) (table 2), an estimated median reduction of 6.8 mmol/mol (95% CI 8.3 to 5.4, p<0.001) (table 3). The MBG decreased to 9.2 mmol/L

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Table 4 Comparing the time and associated costs required to educate Group B (n=91) using the flexible virtual flipped learning programme with what would have been required if the manufacturer supported didactic teaching programme was used

	Per CYP educated in a group of four	The 79 CYP in group B choosing virtual flipped learning	Per CYP requiring one-to-one education delivered inperson	The 12 CYP from group B requiring one-to-one inperson education
Education delivery				
Hours of manufacturer supported didactic teaching programme education time (Band 6/7 nurse or dietitian costs £21 per hour)	5 hours (£105)	395 hours (£8295)	9 hours (£189)	108 hours (£2268)
Hours of flexible virtual flipped learning programme education time (Band 6/7 nurse or dietitian costs £21 per hour)	2.5 hours (£53)	197.5 hours (£4147)	9 hours (£189)	108 hours (£2268)
Hours saved using the flexible virtual flipped learning programme education time (Band 6/7 nurse or dietitian costs £21 per hour)	2.5 hours (£53)	197.5 hours (£4147)	0 hours (£0)	0 hours (£0)

CYP, children and young people.

(IQR: 8.5, 9.8) (table 2), an estimated median reduction of 1.5 mmol/L (95% CI 1.8 to 1.2, p<0.001) (table 3). The TAR lowered to 34.5% (SD: ±11.3) (table 2 and figure 2B), a drop of 16.8% (95% CI 19.2% to 14.4%, p<0.001, table 3). The TAR2 reduced to 11.0% (IQR: 7.0, 17.0) (table 2 and figure 2A), an estimated median drop of 11.0% (95% CI 13.0% to 8.5%, p<0.001) (table 3). The TITR increased to 43.7% (SD: ±9.8) (table 2 and figure 2B), an improvement of 15.7% (95% CI 13.9% to 17.5%, p<0.001) (table 3). The TIR increased to 63.7% (SD: ±11.0) (table 2 and figure 2B), an improvement of 17.2% (95% CI 15.0% to 19.4%, p<0.001) (table 3). No changes were observed for TBR2, TBR, and COV as detailed in tables 1–3.

Comparing Group A versus Group B

Demographics of Group A versus Group B

Group A had fewer CYP from black ethnic background (p<0.05) in comparison with Group B. The Group A cohort demonstrated a higher IMD Score (p<0.05), alongside the primary carers having higher educational attainment (p<0.01) (table 1). A higher proportion of CYP in Group B were using CSII at baseline (p<0.01) and had a shorter duration of diabetes (p<0.05) (table 1). Before initiating AID therapy, Group A had a median CGM usage of 9 months (IQR: 7, 10), which was significantly less than Group B's median of 18 months (IQR: 12, 24) (p<0.001). There was a notable difference in AID system selection (p<0.001); Group A predominantly opted for CIQ, while Group B opted for OP5 (table 1). Out of the 74 and 91 CYP who were educated in Groups A and B, only 6 (8%) and 12 (13%) received education on a one-to-one basis through the inperson method, respectively. This choice was primarily due to the need for an interpreter (Group A=5, Group B=10). The 74 CYP in Group A were onboarded over 24 months at a rate of 18.5 per 6 months. In contrast, all of Group B were onboarded in 6 months, making a rate of 94 per 6 months.

Baseline glucose metrics of Group A versus Group B

All glucose metrics, except TAR2, were comparable between the two groups at baseline (table 1). Group A's TAR2 was 19.0% (IQR: 10.0, 29.0), which was significantly lower (p<0.05) than Group B's TAR2 at 22.0% (IQR: 15.0, 36.0).

90-day AID glucose metrics of Group A versus Group B

All glucose metrics, except COV, were comparable between the two groups after 90 days of AID initiation (table 1). Group A's COV was 37.6% (IQR: 34.3, 41.4), which was significantly lower (p<0.05) than Group B's COV of 39.6% (IQR: 36.5, 43.2).

Comparing the change in glucose metrics over 90 days of Group A versus Group B

All glucose metrics, except TITR, were comparable between the two groups from baseline to the 90-day mark (table 3). Group A's improvement in TITR from baseline to 90 days of 11.7% (95% CI 8.9% to 14.5%, p<0.001) was lower than Group B's improvement of 15.7% (95% CI 13.9% to 17.5%) a difference of 4.0% (95% CI 7.1% to 0.8%, p<0.05).

A separate analysis was conducted to assess if the 18 CYP educated on a one-to-one basis by the inperson programme affected the glycemic outcomes. Removal of the 18 CYP did not change any of the glycemic indices.

Group A versus B onboarding time

The 79 (87%) CYP from Group B selecting the virtual flipped learning programme required half the time

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commitment from diabetes educators than if they were educated using the manufacturer-supported didactic teaching programme. For CYP onboarded in a group of four, educators spent 2.5 hours per CYP for the virtual programme versus 5 hours for the inperson programme, as detailed in table 4. This equated to a total time saving of 197.5 hours for diabetes educators (table 4). By choosing the virtual flipped learning programme, each family reduced their education time by 3 hours and saved approximately 8 hours of travel time to the hospital by four avoided trips (figure 1). The 12 families who selected the one-to-one model did not experience any time savings. The virtual model also enabled all sessions except the onboarding session to be conducted after school hours, potentially reducing school absences and the need for parental time off work. However, this benefit was not quantitatively assessed due to the lack of robust data collection for an accurate analysis.

Group A were onboarded at a cadence on 18.5 CYP per 6 months. In contrast Group B were onboarded at 94 CYP per 6 months, representing a fivefold higher onboarding cadence.

Cost analysis

With 87% of Group B opting for the virtual flipped learning programme, a total saving of £4147 was achieved through 197.5 hours saved. However, this saving was offset by the £4600 cost of developing the programme, which involved 200 hours of work by a Band 7 specialist, priced at £23 per hour. Full details of the cost analysis are available in table 4. No time or cost saving was realised for families who selected the inperson model.

DISCUSSION

Our report presents an innovative approach to AID onboarding, employing a flexible virtual flipped learning approach to expand capacity through creative and proven effective methods. It demonstrates that a flexible virtual flipped learning programme effectively improves glycemic control in CYP with T1D initiating on AID systems. The glycemic improvements observed with this method are comparable to those achieved through manufacturer-supported didactic teaching programmes but offers a significant advantage owing to its flexibility to support those with greater needs such as CYP from lower SES, ethnic minority backgrounds, or with carers of lower educational achievement. The two-pronged approach where the vast majority select virtual flipped learning thereby creating capacity to offer an inperson programme to those most in need addresses inequitable access to advanced diabetes technologies.

Both manufacturer-supported didactic teaching and flexible flipped learning programmes offer significant improvements in glycemic control with the latter offering more flexibility. The approximate 14% increase in TIR and reduction in TAR from baseline that we noted with both groups mirrors the results of the recent meta-analysis.[15] The absolute TIR after 90 days was around 64% for both groups which aligns closely with the 65% TIR seen in CYP in the UK national pilot.[14]

The flexible approach, combining virtual and inperson elements, significantly enhanced access to AID systems for CYP from demographics that are often under-represented or have limited access to advanced diabetes technologies.[22] Becoming independent of manufacturer support with education delivery, by implementing a virtual flipped learning programme, halved the onboarding time and allowed quicker access to AID therapy for those CYP who are usually the last to avail the benefits of advanced technology. Our hybrid model meets the education requirements set out in NICE Technology Appraisal 943 for AID systems.[16] It provides both face-to-face and virtual training options, ensuring fair and equitable access for people from all demographic groups. Moreover, our 6 monthly onboarding cadence was fivefold higher with the hybrid model, allowing us to initiate more CYP in 6 months than we did in 2 years with the traditional method. The 200 hours invested in developing the virtual programme were recouped within 6 months, and we anticipate saving an additional 200 hours over the next year as we onboard the remaining 90–100 CYP to the AID systems. Additionally, we expect to save approximately 60 hours annually, after accounting for an approximate of 20 hours for updates, as we typically see 40 newly diagnosed CYP with T1D each year.

In our cohort, the more marginalised group were on CGM twice as long as the more affluent group before upgrading to AID therapy which highlights the differential onboarding. Our center, like most other centers, has historically favored technology appraisal in CYP from more affluent backgrounds and those with higher parental education status which could be attributed to various factors. The additional time required to onboard families who need one-to-one support coupled with the limited availability of manufacturer supported educators is a major factor. Additional considerations include the potential bias due to pre-existing notion among healthcare professionals regarding the level of parental education and language proficiency required for technology use.[35] Inspecting our clinical practice allowed us to create a hybrid programme which increases capacity, enabling one-to-one education for marginalised groups leading to successful use of AID therapy. We anticipate these results will encourage professionals to re-evaluate their practice to offer diabetes technology equitably.[35]

The improved TITR observed in Group B in comparison to Group A over 90 days of using the AID systems might be explained by differences between AID system settings that influence the algorithm. Mainly, Group B used the OP5 system, with a usage rate of 79%. The OP5 targets the exact user-set target glucose level (exclusively set at 6.1 mmol/L in Group B). Furthermore, the OP5 system automatically adjusts

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insulin based on its built-in algorithm that determines basal insulin level and the insulin sensitivity factor. In contrast, the majority of Group A (84%) used the CIQ system, which doesn't automatically increase insulin when glucose levels are between 6.3 mmol/L and 8.9 mmol/L. Moreover, insulin adjustments by the CIQ algorithm primarily depend on the insulin sensitivity factor and basal rate, which are set and updated by the user or diabetes team.

Our report is limited by its retrospective nature, and lack of randomised comparison. The data cover only the first 90 days of AID usage and long-term data are lacking. A prospective multicenter cluster randomised trial would enable a more conclusive determination of whether the virtual hybrid model can yield comparable results on a more generalizable scale throughout the UK. However, data from meta-analyses, real-world studies and a national pilot show that glycemic improvements attained at 3 months persist for up to 2 years.[14 15 36 37] As highlighted in the methods section, the GMI formula is based on data from white European individuals with diabetes.[33] Hence, caution should be exercised when interpreting improvements based solely on GMI in an ethnically diverse population. A significant discrepancy of at least 5 mmol/mol between GMI and HbA1c measurements in 26%–68% of patients with diabetes has been reported.[38] Nonetheless, our data are complemented by full CGM glucose metrics in addition to GMI.

A notable limitation is the lack of material in multiple languages, preventing those requiring an interpreter benefitting from virtual flipped learning and reduction in education and travel time.

CONCLUSIONS

Our report confirms the efficacy of a flexible virtual flipped learning programme in facilitating AID onboarding equitably. The virtual flipped learning model is not only effective but also halves the time commitment needed from diabetes educators, CYP and their caregivers. Additionally, this model eliminates the need for manufacturer-provided clinical educators, whose availability can often be difficult to coordinate thereby limiting flexibility. The capacity created through flipped learning can be used to ensure equitable onboarding of CYP and families with additional needs. Given the anticipated widespread implementation of AID systems for CYP across the UK, generating capacity is crucial. We highlight a scalable solution that could help avoid unequal access to technology, a key concern that the NHSE Core20PLUS5 programme aims to address.

Crucially, this report provides essential insights into optimising AID system onboarding and offers a valuable reference point for services aiming to address inequity in advanced diabetes technology provision.

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Acknowledgements The authors thank the Diabetes Team at Birmingham Women's and Children's hospital for delivery of the AID teaching programmes and the clinicians involved in care delivery, for their contribution. The authors also thank Francesca Annan and Rebecca Martin from the University College of London Diabetes Team who collaborated on creating the starting dose calculator and clinical tool for assessing AID system downloads. The authors also thank all the CYP with T1D and their families for their feedback on the education approaches.

Contributors JP: Design, background research, data collection, statistics, manuscript writing. LC: Design and manuscript writing. LD, RPD, RK, MK: Manuscript review. SU: Design, statistics, manuscript writing, intellectual revision. All authors were involved in the approval of the final version for publication. SU serves as the guarantor for the content of this article.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests JP: Advisory Board for ROHCE and speaker payments for Dexcom.

Patient consent for publication Not applicable.

Ethics approval This project received approval as a service development initiative from our institutional audit committee (CARMS-31489).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

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Supplementary Materials

Resources for the Virtual Flipped Learning Programme are accessible via a Google Drive link to help support innovation of other teams. However, the material provided by Birmingham Women's and Children's Foundation Trust Diabetes team do not create a therapeutic agreement, as they are designed solely for informational use only.

Resources	Description
Step-by-step teaching guides	The educational content was developed using methods outlined in the ATTD consensus on AID technologies (1) and the UK Diabetes Technology Network's Best Practice Guidelines (2). These resources cover a range of topics including AID expectations, hypoglycaemia and hyperglycaemia management, infusion site care, nutrition advice, CGM management, and analysis of downloaded data. Exercise management advice was based on the ISPAD 2022 Exercise guidelines (3) and a detailed practical guide (4). The materials also encompass GAME-SET-MATCH strategies for optimising TIR (5–7) and a Mealtime Insulin Guide for T1D (8). To cater to different learning styles, we included picture guides and YouTube video links to manufacturers educational material. Additionally, we produced brief educational videos (5-10 minutes) to ensure clarity and consistency in advice, which are accessible on www.screencast-o-matic.com (annual cost of approximately £100 to host the videos) Each AID system [780G, CAMS (under construction), CIQ, and OP5] received a custom teaching guide, reviewed by the respective manufacturer's education team. The Diabetes Team and CYP participating in the education sessions continually evaluated and enhanced these materials over a six-month period.
Survive and Thrive Guides	A crucial tool for CYP was the customised "Survive and Thrive" PDF guide, individually created for each AID system through JavaScript coding and Adobe Acrobat DC (annual cost of ~£180). This interactive guide generates a personalised hypoglycemia treatment plan (5,6) and calculates carbohydrate needs for exercise based the named user's weight, using ISPAD's algorithms (3). It includes QR codes that link to essential short videos (5-10 minutes) covering key management techniques. The "Survive" section of the guide focuses on managing hypoglycaemia and hyperglycaemia, obtaining accurate CGM readings, infusion site management, and essential kit items to carry. The "Thrive" section details crucial nutritional and exercise management strategies, incorporating GAME-SET-MATCH approaches for optimising TIR (5,6) and a Mealtime Insulin Guide for Type 1 Diabetes (T1D). Each AID system, including 780G, CAMS, CIQ, and OP5, has a dedicated version of this guide, which has been reviewed by the education team of each system's manufacturer. The Diabetes Team, along with the CYP participating in the education sessions, continuously reviewed and improved these materials over a period of six months.
Interactive School Careplans	Similar to the "Survive and Thrive" guide, we transformed AID school care plans into interactive PDFs with embedded videos, requiring an 80% competency score for completion, thus reducing the need for direct teaching by healthcare professionals (9).
AID starting settings calculator	We adapted the Automated Insulin Delivery (AID) starting dose calculator originally created by the University College of London's Diabetes Team. This calculator is grounded in the insulin setting guidelines proposed by the ISPAD 2022 guidelines (10) and incorporates research on paediatric bolus calculator settings (11). Our enhancements to the calculator were informed by the ATTD consensus recommendations (1), allowing it to produce tailored initial settings for various AID

	systems that support smooth onboarding.
AID download assessment tool	This starting settings calculator led to the development of a download assessment clinical tool. We integrated the calculator's algorithms with our understanding of factors influencing automated mode and manual mode adjustments in AID systems (1). The download assessment tool provides users with insights into which settings affect Automode for the different AID systems. It also offers tailored suggestions for optimising glucose control. These suggestions are based on several factors: current TIR, total daily insulin dose, desired percentage of basal insulin, and the specific AID system in use. The tool thus serves as an efficient guide for clinicians in supporting CYP make effective adjustments to their AID systems.
Google Forms	We developed Google Forms for AID system selection and pre-initiation education, incorporating teaching guide materials, current insulin settings, setup guides, links to AID simulator applications, and an automated quiz with an 80% pass requirement for progression to onboarding. The forms also facilitated efficient organisation of onboarding sessions. Links to examples: • AID System Selection Google Form Prototype • 780G Pre-AID Education Google Form Prototype • OP5 Pre-AID Education Google Form Prototype • CIQ Pre-AID Education Google Form Prototype • CamAPS FX (under construction)

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