

Long-term outcome of insulin pump therapy in children with type 1 diabetes assessed in a large population-based case–control study

Stephanie R. Johnson · Matthew N. Cooper ·
Timothy W. Jones · Elizabeth A. Davis

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Abstract

Aims/hypothesis We determined the impact of insulin pump therapy on long-term glycaemic control, BMI, rate of severe hypoglycaemia and diabetic ketoacidosis (DKA) in children.

Methods Patients on pump therapy at a single paediatric tertiary hospital were matched to patients treated by injections on the basis of age, duration of diabetes and HbA_{1c} at the time of pump start. HbA_{1c}, anthropometric data, episodes of severe hypoglycaemia and rates of hospitalisation for DKA were collected prospectively.

Results A total of 345 patients on pump therapy were matched to controls on injections. The mean age, duration of diabetes at pump start and length of follow-up were 11.4 (±3.5), 4.1 (±3.0) and 3.5 (±2.5) years, respectively. The mean HbA_{1c} reduction in the pump cohort was 0.6% (6.6 mmol/mol). This improved HbA_{1c} remained significant throughout the 7 years of follow-up. Pump therapy reduced severe hypoglycaemia from 14.7 to 7.2 events per 100 patient-years ($p < 0.001$). In contrast, severe hypoglycaemia increased in the non-pump cohort over the same period from 6.8 to 10.2 events per 100 patient-years. The rate of hospitalisation for DKA was lower in the pump cohort (2.3

vs 4.7 per 100 patient-years, $p = 0.003$) over the 1,160 patient-years of follow-up.

Conclusions/interpretation This is the longest and largest study of insulin pump use in children and demonstrates that pump therapy provides a sustained improvement in glycaemic control, and reductions of severe hypoglycaemia and hospitalisation for DKA compared with a matched cohort using injections.

Keywords Adolescents · Children · Continuous subcutaneous insulin infusion · Hypoglycaemia · Insulin pump · Metabolic control · Type 1 diabetes

Abbreviations

BD	Injections twice daily
CDC	Centre for Disease Control
CSII	Continuous subcutaneous insulin infusion
DKA	Diabetic ketoacidosis
MDI	Multiple daily injections
PMH	Princess Margaret Hospital
RCTs	Randomised controlled trials
TDS	Injections three times daily
WACDD	Western Australia Childhood Diabetes Database

S. R. Johnson · M. N. Cooper · T. W. Jones · E. A. Davis (✉)
Department of Endocrinology and Diabetes, Princess Margaret
Hospital for Children, Roberts Road, Subiaco,
Perth, WA, Australia 6008
e-mail: Elizabeth.Davis@health.wa.gov.au

M. N. Cooper · T. W. Jones · E. A. Davis
Telethon Institute for Child Health Research, Centre for Child
Health Research, The University of Western Australia,
Perth, WA, Australia

T. W. Jones · E. A. Davis
The School of Paediatrics and Child Health, The University of
Western Australia, Perth, WA, Australia

Introduction

The increasing use of insulin pump therapy over the last 15 years, particularly in children, has been driven by improvements in pump technology and the availability of insulin analogues, along with the results of the Diabetes Control and Complications Trial (DCCT), which established the benefit of improved glycaemic control [1, 2]. Despite this increased use, the outcomes of pump therapy continue to be debated. Most studies report an improvement in HbA_{1c}

associated with pump therapy [3–5], although some report no improvement or an initial improvement followed by a return to pre-pump levels after a short time [6–9]. Reports have also suggested that insulin pumps may be associated with a reduction in severe hypoglycaemia [3, 10, 11]. Most studies, however, have been of short duration; very few with greater than 4 years of follow-up. Thus, and particularly in children, there are few studies investigating the long-term impact of insulin pump therapy.

Princess Margaret Hospital (PMH) is the only paediatric referral centre for diabetes servicing the entire state of Western Australia. Previous studies from this centre have confirmed a case ascertainment of greater than 99% [12]. This enables analysis of a population-based cohort. Data are collected prospectively at each visit and entered into the Western Australian Childhood Diabetes Database (WACDD). Pump therapy was introduced at our centre in 1999. We have previously reported on the first 100 patients who commenced pump therapy at our institution [3]. Over the 2 year follow-up presented in that study, patients on pump therapy had a reduction in HbA_{1c} of 0.5% (5.5 mmol/mol) and a 65% reduction in episodes of severe hypoglycaemia. There were also improvements in components of the Diabetes Quality of Life assessment. A limitation of this study, as with most other reports, was the short period of follow-up. In addition, the first 100 patients to commence pump therapy in our centre may have been subject to some selection bias. This current report takes advantage of access to a large population-based sample and aims to determine the long-term impact of insulin pump therapy on diabetes outcomes over a 7 year period.

Methods

Study design

Using a case–control design, we matched patients already commenced on insulin pump therapy with patients on injection therapy. Only patients who commenced insulin pump therapy at least 6 months after diagnosis and with a minimum of 6 months of data on their pump therapy were included in the analysis. Patients on insulin pump therapy were matched to patients on injection therapy on the basis of age (within 1 year), duration of diabetes (within 2 years) and HbA_{1c} at the time of pump start (within 1.5%).

Patients on injection therapy were further subdivided into those on a basal bolus regimen of multiple daily injections (MDI) or those on injections twice daily (BD) or injections three times daily (TDS) according to their therapy at the time their matched pump patient began insulin pump therapy.

As this is an observational study where the source of data is a paediatric clinical database, the data are subject to natural

attrition. For example, patient data collection ceases when a patient leaves the state or upon transition to an adult clinic (at approximately age 18 years) or at the end of the study period (January 2011).

Data are only displayed at each time-point when available for both pump and non-pump match; the longest period of paired data available was 7 years. Matching was performed using a custom random-sampling matching algorithm implemented in R 2.15.1 (www.R-project.org) [13], which minimised the mean difference in HbA_{1c} at the time of pump start across all participants in the study.

Data

Clinical data were obtained from the WACDD. Consent for data to be entered into the database was obtained from all parents or guardians, and data collection was approved by the institution's ethics committee. Fields extracted from the WACDD included patient height and weight, episodes of hypoglycaemia, HbA_{1c}, insulin dose, episodes of diabetic ketoacidosis (DKA) and demographic details. Severe hypoglycaemia was defined as an event resulting in coma or convulsion.

All children have HbA_{1c} measured in clinic every 3 months by agglutination inhibition immunoassay (Ames DCA 2000; Bayer, Mishawaka, IN, USA), calibrated to DCCT-equivalent numbers. HbA_{1c} was also taken at the time of pump start. HbA_{1c} values closest to each specified time-point were used. HbA_{1c} at the time of pump start for the pump patient or his/her matched control was taken as that determined within 45 days of this date. For those who did not have an appointment during this time, the value was taken as the average of the HbA_{1c} measurements before and after the date, within 3 months of the date of pump start.

Protocol for pump therapy

Prior to commencing pump therapy all patients are assessed by the multidisciplinary team for suitability for pump therapy. Insulin pumps are funded through private health insurance or, if not available, by donation. The cost of the consumables is subsidised by the Australian government National Diabetes Supply Scheme. Initially all pump starts were performed in an inpatient set-up, during which time patients had glucose monitoring and further education. Patients were then followed with daily telephone calls for a week following discharge and were seen in the clinic again within a fortnight. From 2008 we moved to a day-only admission for pump starts. The patient and family undergo outpatient education with the dietitian and educators prior to commencing pump therapy. They then have access to daily phone contact with the educators for therapy adjustment.

Analysis

Statistics were analysed using SPSS for Windows (Version 19.0; SPSS, Chicago, IL, USA). BMI standard deviation scores (z scores) were obtained using the Epi Info (Version 7.1.2; Centers for Disease Control and Prevention, Atlanta, GA, USA) program based on 2000 Centre for Disease Control (CDC) growth charts from the CDC website (www.cdc.gov/growthcharts), accessed 16 October 2012.

Data are presented as mean \pm SD. Change in HbA_{1c} was analysed using a paired t test of the difference in HbA_{1c} between the pump and matched non-pump groups (i.e. the injection group as a whole or the MDI or the BD/TDS groups) at pump start and each specified time-point. Differences in DKA and hypoglycaemia rates were analysed using a χ^2 test. Values of $p < 0.05$ were considered significant.

Results

Participant characteristics

Altogether, 502 patients attending PMH Diabetes Clinics from January 1999 to January 2011 used insulin pump therapy. Data from 98 patients were excluded from the analysis as they did not meet the inclusion criteria. Thus 45 patients commenced pump therapy within 6 months of diagnosis, 43 had less than 6 months of data since starting pump therapy and ten began pump therapy at another centre. Of the 404 eligible patients, matches within the defined thresholds were available for 345.

By design, the pump and non-pump cohorts were well matched for baseline characteristics (Table 1), with no significant difference in age at pump start (11.5 vs 11.5 years, $p = 0.95$), duration of diabetes (4.1 vs 4.1 years, $p = 0.89$) and duration of follow-up (3.5 vs 3.6 years, $p = 0.23$). The pump therapy cohort had a greater percentage of girls than the non-pump cohort (56% vs 48%, $p = 0.016$). This reflects the sex distribution among clinic patients as a whole. Thus 56% of the pump population in the study were female, compared with 54% for the clinic's whole patient population ($p = 0.63$). At the time of pump start, there was no difference between the pump and non-pump cohorts for HbA_{1c} (8.0 vs 8.0% [63.9 vs 63.9 mmol/mol], $p = 0.57$), BMI z score (0.69 vs 0.78, $p = 0.11$) or the rate of hospitalisation for DKA in the year prior to pump therapy (2.0 vs 1.1 per 100 patient-years, $p = 0.37$). In the year prior to commencing pump therapy, the pump group had a higher rate of severe hypoglycaemia than the non-pump cohort (14.7 vs 6.8 events per 100 patient-years, $p = 0.001$) (Table 2).

Patients on injection therapy at our clinic comprise those on BD, TDS or MDI. At the time when matched pump patients began insulin pump therapy, 63% of the injection

Table 1 Baseline characteristics of pump and non-pump participants at the time of pump start

Demographics	Pump cohort	Matched non-pump cohort	p value
n	355	355	
Age at diagnosis (years)	7.3 (3.5)	7.4 (3.5)	0.859
Age at pump start (years)	11.5 (3.7)	11.5 (3.7) ^b	0.952
Diabetes duration at pump start (years)	4.1 (3.0)	4.1 (3.0) ^b	0.891
Length of follow-up (years)	3.5 (2.5)	3.6 (2.5)	0.229
Sex			0.016*
Girls (n)	200	169	
Boys (n)	155	186	
HbA _{1c} (%)	8.0 (1.0)	8.0 (1.0)	0.566
HbA _{1c} (mmol/mol)	63.9 (10.9)	63.9 (10.9)	
Severe hypoglycaemia rate ^a	14.7	6.8	0.001**
DKA hospitalisation rate ^a	2.0	1.1	0.366
BMI z score	0.69 (0.79)	0.78 (0.83)	0.113

Unless otherwise specified, data are displayed as mean \pm SD

* $p < 0.05$, ** $p < 0.01$

^aRate per 100 patient-years

^bWithin the matched non-pump cohort, pump start refers to the date the matched pump patient (for those on injection therapy) started insulin pump therapy

group were on BD or TDS regimens and 37% on MDI. Insulin glargine (A21Gly,B31Arg,B32Arg human insulin) was introduced at our practice in 2003, replacing NPH insulin as the long-acting insulin for the MDI group and resulting in wider use of the MDI regimen. There was no significant difference for age at pump start in the pump vs MDI sub-cohort (13.4 vs 13.3 years, $p = 0.22$) or the pump vs BD sub-cohort (10.3 vs 10.3 years, $p = 0.47$). However, the age at pump start was younger for the BD/TDS groups and their matching pump group compared with the MDI and their matching pump groups ($p < 0.001$).

Of the 345 patients on pump therapy, 38 ceased pump therapy during the course of the study; six of these were in the 1st year of treatment, seven in the 2nd year and ten in the 3rd year, while the remainder had had at least 3 consecutive years on pump therapy before discontinuing.

Glycaemic control

Figure 1 shows the mean HbA_{1c} for the pump and non-pump cohorts over the 7 years of follow-up, shown 3-monthly until 12 months, 6-monthly until 2 years and yearly thereafter. Figure 1a compares all patients on injection therapy with their matched pump patient. Both groups had a similar HbA_{1c} at the time of pump start. The mean difference in

Table 2 Rates of severe hypoglycaemia and DKA, as well as BMI z scores and insulin doses in study groups

Variable	Pump cohort	Matched non-pump cohort	<i>p</i> value (pump vs non-pump)
Rate of severe hypoglycaemia^a			
12 months prior to pump start	14.7	6.8	0.001**
After pump start	7.2 [†] *	10.2	0.013*
DKA hospitalisation^a			
12 months prior to pump start	2.0	1.1	0.366
After pump start	2.3	4.7 [†] *	0.003**
BMI z score			
12 months prior to pump start	0.69 (0.79)	0.78 (0.83)	0.139
After pump start	0.70 (0.77)	0.71 (0.87)	0.843
Insulin dose (units/kg)			
12 months prior to pump start	0.97 (0.34)	0.96 (0.34)	0.778
After pump start	0.89 (0.23) [†] *	1.08 (0.29) [†] *	<0.001***

Data are given as rates (hypoglycaemia, DKA) or mean (SD); ‘after pump start’ refers to the final BMI z score or final insulin dose or rate of hypoglycaemia or DKA over the 1,160 patient-years of follow-up

p*<0.05, *p*<0.01, ****p*<0.001

[†] Significance (within cohort) between period prior to pump start and after pump start *p*<0.05

^a Rate per 100 patient-years.

HbA_{1c} between the pump and non-pump cohort was 0.6% over the 7 years of follow-up. Once on insulin pump therapy, the pump cohort had a significantly improved HbA_{1c} at all time-points (inclusive) through to the final 7 year follow-up comparison, with an initial rapid improvement in the pump vs non-pump groups of 0.6% (6.6 mmol/mol) at 3 months (*p*<0.001). The level of improvement was lowest at 2 years, although still significant at 0.3% (3.3 mmol/mol, *p*=0.01). The improvement in the pump cohort increased from years 2 to 7, reaching a maximum of 1.0% (10.9 mmol/mol, *p*<0.01) at 6 years. In absolute terms the lowest HbA_{1c} in the pump cohort was achieved at 3 months at 7.6% (59.6 mmol/mol); at 2 years the value rose to 8.1% (65.0 mmol/mol), being maintained thereafter at between 7.7% (60.7 mmol/mol) and 8.1% (65.0 mmol/mol). In the injection cohort, however, the mean HbA_{1c} continued to increase over time from 8.0% (63.9 mmol/mol) at pump start to 8.8% (72.7 mmol/mol) at 7 years.

When compared with MDI therapy (Fig. 1b), participants using insulin pumps had a significantly improved HbA_{1c} at all time-points (except 18 months and 2 years) up to 5 years. The mean improvement in HbA_{1c} over the 5 years was 0.7% (7.7 mmol/mol). This difference peaked at 5 years when the difference in HbA_{1c} was 1.8% (7.8 vs 9.6%

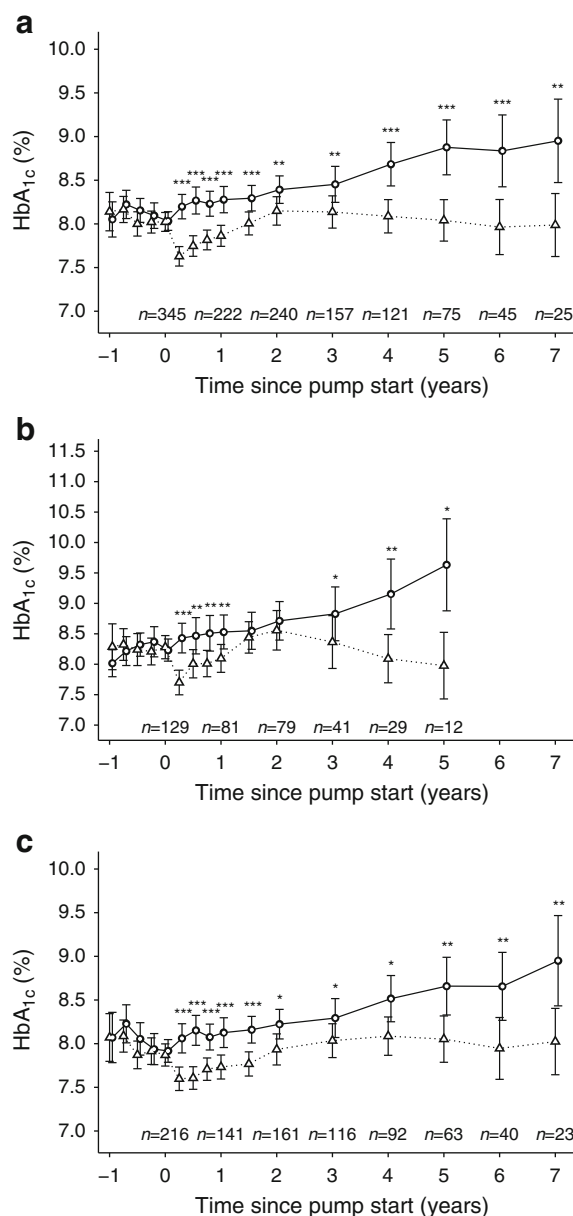


Fig. 1 Mean HbA_{1c} (%) with 95% CI (calculated as $\pm 1.96 \times \text{SEM}$) for the pump (dotted lines, triangles) and non-pump (continuous lines, circles) cohorts from time of pump start for 7 years of follow-up. (a) Pump therapy patients and all non-pump therapy patients (*n*=345). (b) Pump therapy patients and MDI therapy patients (*n*=129). Follow-up was limited to 5 years as group size thereafter was fewer than five. (c) Pump therapy patients and BD/TDS injection therapy patients (*n*=216). To convert values for HbA_{1c} in % into mmol/mol, subtract 2.15 and multiply by 10.929. **p*<0.05, ***p*<0.01, ****p*<0.001

[62 vs 81 mmol/mol]). The analysis and data presentation comparing pump and MDI patients were limited to 5 years, as in subsequent years less than five matched pairs were available.

Compared with BD/TDS therapy, the insulin pump cohort had a significantly improved HbA_{1c} at all time-points to 7 years (Fig. 1c). The mean difference over this time was 0.5% (5.5 mmol/mol).

Hypoglycaemia

The rate of severe hypoglycaemia was higher in the pump group prior to commencing insulin pump therapy (14.7 vs 6.8 events per 100 patient-years, $p < 0.001$). After starting pump therapy, the rate of hypoglycaemia decreased in the pump cohort to half of that in the year before pump therapy (14.7 to 7.2 events per 100 patient-years, $p < 0.001$). Severe hypoglycaemia increased in the non-pump cohort over the same period from 6.8 to 10.2 events per 100 patient-years. The rate of hypoglycaemia was also 30% lower in the pump cohort than in the non-pump cohort over the 1,160 patient-years of follow-up (7.2 vs 10.2 per 100 patient-years, $p = 0.013$).

Complications

The rate of hospitalisation for DKA was the same for the two groups prior to pump therapy. However, the rate of hospitalisation for DKA increased in the non-pump cohort (pre-pump 1.1, post-pump 4.7 events per 100 patient-years, $p < 0.001$), but not in the pump cohort (pre-pump 2.0, post-pump 2.3 events per 100 patient-years, $p = 0.69$). Thus over the 1,160 patient-years of follow-up, the hospitalisation rate for DKA for those on continuous subcutaneous insulin infusion (CSII) was half that of those using injections (2.3 hospitalisations per 100 patient-years compared with 4.7 for those on injections, $p < 0.01$).

There was no significant difference in BMI z score for those on pump or injection regimens at baseline or over the follow-up period. The insulin dose requirement was lower in the pump than in the non-pump cohort ($p < 0.001$). Upon initiation of pump therapy, the insulin requirement in the pump cohort fell by 9% (in units/kg) ($p < 0.001$), compared with an 11% increase in non-pump patients over the follow-up period ($p < 0.001$).

Clinical and demographic factors associated with outcomes of pump therapy

Glycaemic control As shown in Fig. 2, a significant relationship was seen between HbA_{1c} at commencement of insulin pump therapy and the magnitude of HbA_{1c} improvement (Fig. 2a–c). Patients who had an HbA_{1c} of $\geq 8.5\%$ (69.4 mmol/mol) at the time of pump start had the greatest reduction in HbA_{1c} (up to 0.9% [9.8 mmol/mol]) compared with their matched controls. This result was also significant until 4 years of follow-up ($p = 0.01$). Those who began the pump with an HbA_{1c} of $< 7.5\%$ (58.5 mmol/mol) had no significant improvement compared with their non-pump controls. Patients with an HbA_{1c} of 7.5 to 8.4% (58.5–68.3 mmol/mol) at pump start had a significant reduction

($p < 0.001$) in HbA_{1c} at 3 to 12 months (0.4–0.7% [4.4–7.7 mmol/mol]).

Age With respect to different age groups, the older age groups (6–12 years and > 12 years) had the biggest initial improvement of glycaemic control compared with the < 6 -year age group upon commencement of insulin pump therapy, with HbA_{1c} decreasing by 0.6 to 0.8% (6.6–8.7 mmol/mol) within 3 months (Fig. 2d–f). Over the following 5 years, each age group on the pump showed an improvement compared with non-pump counterparts. However, the initial HbA_{1c} was lowest in the < 6 -year-old group, followed by the 6 to 12 year olds and then the > 12 year olds. The mean HbA_{1c} of the < 6 -year-old pump cohort remained below 7.5% (58.5 mmol/mol) from 6 months through the first 5 years of follow-up, in keeping with international guidelines for the management of children and adolescents with type 1 diabetes [14].

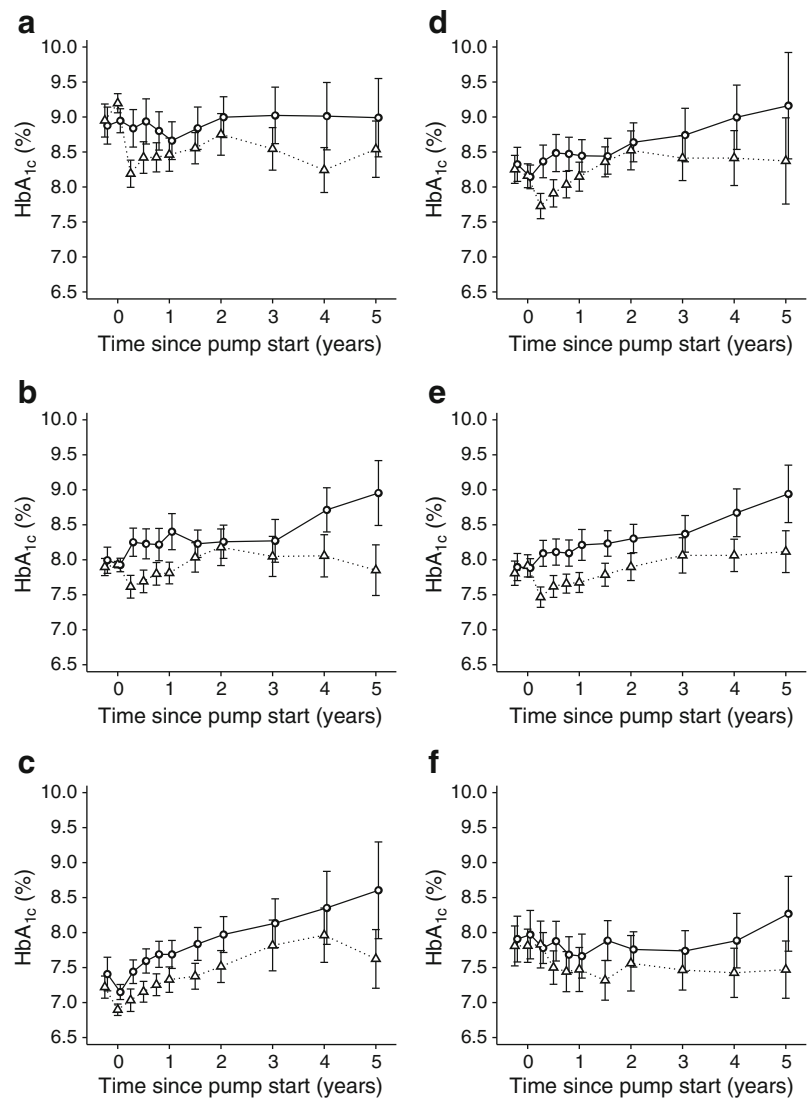
Discussion

This is the largest study of insulin pump use in children. It also has the longest follow-up period of any study of insulin pump therapy in children. Our data confirm that insulin pump therapy improves glycaemic control, with improvements being sustained for at least 7 years. Although this was not a randomised trial, it does reflect ‘real life’ experience in a large population-based sample over a prolonged period and as such provides important information.

The mean improvement in HbA_{1c} of 0.6% (6.6 mmol/mol) in the pump cohort is in keeping with other studies [3, 10, 11]. This magnitude of change is clinically significant, as the DCCT has reported reductions in microvascular complications of 21 to 49% with every 1% reduction in HbA_{1c} [15]. The reduction in HbA_{1c} in CSII compared with MDI groups in our study was consistent with other studies, with a mean improvement of 0.7% (7.7 mmol/mol) over 5 years. A meta-analysis of paediatric and adult studies by Pickup revealed a 0.6% (6.6 mmol/mol) improvement in HbA_{1c} for CSII compared with MDI therapy [10]. This analysis included observational studies, as well as randomised controlled trials (RCTs). A meta-analysis of RCTs alone revealed a mean HbA_{1c} improvement of 0.2% (2.2 mmol/mol) over the length of the respective studies, which were all of less than 12 months duration [16]. There are very few RCTs of CSII versus MDI in children, and all are of less than 12 months duration [5–7, 17].

The initial immediate reduction in HbA_{1c} has been well described in previous observational studies and some RCTs [3, 8, 11, 18, 19]. Prior to commencing pump therapy, all patients at our institution are assessed by our treating team for suitability for insulin pump therapy. All families undergo

Fig. 2 Mean HbA_{1c} (%) with 95% CI (calculated as $\pm 1.96 \times \text{SEM}$) for the pump (dotted lines, triangles) and non-pump (continuous lines, circles) cohorts from the time of pump start for 5 years of follow-up. (**a–c**) Values are presented according to the HbA_{1c} value at time of pump start, i.e. values are for those with (**a**) HbA_{1c} >8.5% (69.4 mmol/mol, $n=112$), (**b**) HbA_{1c} 7.5 to 8.4% (58.5 to 68.3 mmol/mol, $n=132$) and (**c**) HbA_{1c} <7.5% (58.5 mmol/mol, $n=108$). (**d–f**) Values are presented according to age at time of pump start, i.e. values are for those aged (**d**) >12 years ($n=168$), (**e**) 6 to 12 years ($n=150$) and (**f**) <6 years ($n=34$). To convert values for HbA_{1c} in % into mmol/mol, subtract 2.15 and multiply by 10.929



extensive further education and glucose monitoring with diabetes educators and dietitians. The increased education and educator contact may be responsible for some of the early improvement in HbA_{1c}, as studies have confirmed that increased contact with diabetes educators between medical appointments can improve diabetes control [20]. The novelty of this new technology may also increase patient motivation to manage their diabetes in the short term.

Following the initial improvement, HbA_{1c} in the pump patients increased at 2 years. However, it remained 0.3% (3.3 mmol/mol) lower than in the matched non-pump cohort. Sulli and Shashaj also noted a trend for the mean HbA_{1c} to increase at 2 years before improving for the next 2 years of their study [4]. This may be partly due to waning enthusiasm for the new technology. In our study this decline was noted in the pump vs MDI cohort, but not in the pump vs BD/TDS cohort. The former cohort was older and attention to blood

glucose control may be less pronounced in older adolescents, who also have more autonomy in their diabetes management. From years 2 to 7 the mean HbA_{1c} in the pump group showed a further trend towards improvement. However, the group using injection therapy displayed a steady increase in HbA_{1c} over the 7 years of follow-up at a rate of 0.1% (1.1 mmol/mol) per year. As the mean age at pump start was 11.45 years, many of the participants will have reached puberty during these years, when HbA_{1c} frequently increases, reflecting a period of insulin resistance [21, 22]. As such, the difference between the pump and injection cohorts generally becomes greater as time on pump therapy increases. By using matched patients for this analysis, we were able to take into account the natural increase in HbA_{1c} observed over time in this cohort. No RCTs in children that examined this difference over time lasted longer than 12 months.

There is a perception that children with poorer glycaemic control will not benefit from insulin pump therapy. Indeed, patients with poor control are often excluded from trials of insulin pump therapy. However, a number of RCTs and observational studies have revealed that this group frequently has the greatest improvement in glycaemic control with pump therapy [17, 23, 24]. These patients, moreover, are at greatest risk of developing complications and stand to benefit most from a reduction in HbA_{1c} [2]. In absolute terms, the pump cohort in our study who began with an HbA_{1c} of $\geq 8.5\%$ (69.4 mmol/mol) had the greatest reduction in HbA_{1c}, namely up to 0.9% (9.8 mmol/mol) compared with their control group. This result was also sustained for at least 4 years of follow-up (after which the numbers fail to reach significance). Importantly, this improvement was not achieved as a result of deteriorating glycaemic control in the non-pump cohort, which remained static.

In the year prior to starting pump therapy, our patients had double the rate of severe hypoglycaemia. Severe hypoglycaemia, fear of hypoglycaemia or recurrent hypoglycaemia are often reasons for considering insulin pump therapy. Hypoglycaemia is one of the main limiting factors to obtaining optimal metabolic control. In addition, fear of hypoglycaemia can significantly impair the quality of life of the child and its parents [25]. Previous studies have shown a significant improvement in quality of life upon starting insulin pump therapy, in particular with respect to worrying about hypoglycaemia [26]. The clinician's enthusiasm for suggesting insulin pump therapy may be in part due to the reduction in hypoglycaemia observed with pump therapy in previous studies [10].

It is pleasing to see that the improvement in HbA_{1c} was achieved together with a reduction in the rate of severe hypoglycaemia. Once on pump therapy, the rates of severe hypoglycaemia in the pump cohort were 30% lower than in patients on injections and half the rate of that in the pump cohort in the year prior to initiation of pump therapy. Other studies in this field have revealed conflicting results. A meta-analysis of RCTs of CSII vs MDI revealed no significant difference in the rate of severe hypoglycaemia [16]. This may be due to the low baseline rate of hypoglycaemia in those participants, combined with a relatively short follow-up period. Another meta-analysis by Pickup and Sutton revealed a decrease of up to 75% in the pump cohort (adults and children) [10]. This paper included RCTs and observational studies, the latter of which comprise the majority of long-term studies in this area. Their results are more consistent with those of our case-control observational study. There are fewer studies in children on this issue. Again, the available RCTs have not shown a significant reduction in the rate of hypoglycaemia [6, 17], while observational studies have suggested that CSII does indeed decrease the frequency of severe hypoglycaemia [3, 27]. A study of hypoglycaemia in the last 10 years at our institution revealed a lack of

association between rates of severe hypoglycaemia and HbA_{1c} in clinic patients as a whole [28].

There was no significant BMI change in our CSII cohort. However, the mean BMI *z* score of both groups was above the 50th centile for age, consistent with other studies on weight and diabetes [29]. CSII allows greater flexibility with regard to the number and carbohydrate content of meals. One concern is that this greater freedom may cause some patients to take advantage of this situation and consume more food, especially at the start of pump therapy. However, we did not see a significant change in BMI *z* score at any time-point. CSII can also allow patients to have more control over their eating patterns; they may not be required to eat as many meals or snacks to match the less physiological insulin delivery provided by injection therapy.

Patients on insulin pump therapy have a potential risk of line disconnection or pump malfunction with subsequent DKA. However, the rate of hospitalisations for DKA was 50% lower in our pump population. DKA is a preventable complication if blood glucose levels and ketones are frequently monitored. Prior to commencing insulin pump therapy, patients and their families undergo further education and liaise closely with diabetes educators. A key requirement for potential insulin pump therapy users is sufficient motivation and the ability and willingness to test blood glucose levels four times a day. The decreased rate of DKA may be a result of increased education or the increased motivation of patients and families. The non-pump cohort had a significantly increased rate of DKA over the follow-up period. An increase in DKA during adolescence is common [30].

This was an observational trial following patients within our clinic. Patients are transitioned from our children's hospital at approximately age 17 to 18 years. We therefore lack follow-up data for patients after this age. The small numbers of patients remaining after 5 years are those who began pump therapy at least 5 years previously and at an age sufficiently young for them to still be in our clinic 5 years later.

The introduction of insulin glargine (A21Gly,B31Arg, B32Arg human insulin) into clinical practice in 2003 saw an increase in the use of MDI. In our clinical practice, MDI is more commonly used in adolescent patients as opposed to younger children. The combination of older participants and more recent use of MDI resulted in fewer years of follow-up for the MDI vs pump cohort. MDI is commonly referred to as more intensive insulin therapy and is associated with improved HbA_{1c}. While this study did not compare the BD and MDI regimens, it did find that HbA_{1c} was lower in the pump group matched to the BD cohort. However these patients were typically younger than the MDI cohort as explained above.

We conclude that insulin pump therapy is associated with a significant improvement in glycaemic control, which is sustained over many years. In our cohort, this improvement was achieved with reduced rates of severe hypoglycaemia and DKA, without an increase in BMI. Children and adolescents with poor glycaemic control had the greatest reduction in HbA_{1c} with insulin pump therapy.

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