Educational Attainment and Childhood-Onset Type 1 Diabetes

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OBJECTIVE

To quantify associations of educational outcomes with type 1 diabetes status and glycemic management (HbA_{1c}).

RESEARCH DESIGN AND METHODS

This was a record linkage study of schools and higher (college) education data sets linked to national diabetes audits. The population includes all Welsh children attending school between 2009 and 2016, yielding eight academic cohorts with attainment data, including 263,426 children without diabetes and 1,212 children diagnosed with type 1 diabetes. Outcomes include standardized educational attainment for those aged 16 years, higher education participation for those aged ≥18 years, and school absences among those aged 6–16 years.

RESULTS

Comparison between children with type 1 diabetes and children without diabetes showed no strong evidence of associations for student attainment (0.001 SD, 95% CI −0.047 to 0.049, $P < 0.96$, n = 1,212 vs. 263,426) or higher education entry rates (odds ratio 1.067, 95% CI 0.919–1.239, $P < 0.39$, n = 965 vs. 217,191), despite nine more sessions of absence from school annually ($P < 0.0001$). However, attainment in children in the most optimal HbA_{1c} quintile was substantially better than for children without diabetes (0.267 SD, 95% CI 0.160–0.374, $P < 0.001$) while being worse than for children without diabetes in the least optimal quintile (−0.395 SD, 95% CI −0.504 to −0.287, $P < 0.001$). Attainment did not differ by duration of "exposure" to diabetes based on age at diagnosis.

CONCLUSIONS

Despite more school absences, diabetes diagnosis is not associated with educational attainment or entry into higher education, although attainment does vary by HbA_{1c} level, which may be explained in part (or wholly) by unobserved shared personal, family, or socioeconomic characteristics associated with both success in education and effective glycemic self-management.

For children with type 1 diabetes, frequent glycemic excursions outside the normal physiological range may result in the acute metabolic disturbances of hypoglycemia, hyperglycemia, and ketoacidosis, which could impact educational attainment through impaired concentration, absence from school, or hospitalization while efforts are made to correct the metabolic disturbance (1). Furthermore, recurrent episodes of hypoglycemia may cause neuronal injury from neuroglycopenia and hyperglycemia (especially in the context of ketoacidosis) and may damage white matter, disrupt functioning of the blood-brain barrier, and cause cerebral edema during episodes of ketoacidosis.

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Having type 1 diabetes in childhood has been reported to lead to long-term radiological differences in brain structure evident by early adult life (2). Additional studies suggest adverse effects of diabetes on several aspects of cerebral function, including intelligence quotient (IQ), spelling, reading, and arithmetic (3,4), spatial and verbal intelligence (5), memory (6,7), attention (7,8), and behavior (9). Cognitive impairment, particularly in younger individuals with diabetes, has been reported (6,7,10–12). However, educational attainment is a much broader concept than these precisely defined cognitive measures and generating high-quality evidence of the impact of diabetes is more challenging. Some studies used outcome measures that were not from high stakes tests (13,14). "High stakes tests" refers to examinations or assessments that carry important consequences for the individuals taking the tests. For example, high stakes tests at the end of compulsory schooling will influence subsequent educational and employment prospects (15). Such tests are often "standardized," meaning there are specific rules and regulations involved in providing and completing the test allowing better comparison across individuals. Other limitations of the extant evidence included limited comparability across classes due to differences in teacher grading practices such as grade point averages (4) or using opportunistic samples with limited generalizability (16). In a systematic review investigators identified only two high-quality studies using the same Swedish data set (17–19), which showed a significant but substantively small reduction in mean final grades in those with diabetes. Findings from a more recent nationwide study from Scotland showed that those with diabetes experience greater absenteeism and learning difficulties but no difference in exam performance overall, although those in the least optimal HbA_{1c} quintile did show significantly poorer attainment. This study was limited by the definition of academic achievement including qualifications over a range of levels gained during the last 3 years of secondary school categorized as low, basic, broad/general, or high attainment, with such data available for only three academic cohorts, which reduced the analytical sample size. The study also did not include comparison of young people with diabetes in the different HbA_{1c} quintiles with the general population without diabetes.

Socioeconomic factors are also important to address in examining the relationship of diabetes, HbA_{1c}, and educational performance. Although in a recent extensive study from Denmark published after the systematic review was complete Skipper et al. (13) did not find reduced academic performance in children with diabetes, they did find an association between HbA_{1c} status and educational performance. This association was reduced substantially though not completely after adjustment for socioeconomic and personal/family factors including parental age, income, highest completed education, family structure, migrant status, and whether a parent had insulin-dependent diabetes.

In this study, we therefore aimed to evaluate the impact of diabetes on school absenteeism and high stakes assessment at the end of compulsory schooling (age 16 years [since the period of data collection, the age for compulsory education has increased to 18 years]) as well as progression to further education (age 19 years) in a large national cohort of young people diagnosed with diabetes in childhood in comparison with children who did not have diabetes. We also sought to use the repeated assessments made throughout school to take into account the duration of diabetes and also study the effects of socioeconomic status. Our working hypothesis was that diabetes would have a negative association with educational outcomes, in view of the potential effects of low and high glucose levels and ill health on learning cited above.

RESEARCH DESIGN AND METHODS

Study Population and Data Sets

The study population was children in Wales who were of compulsory school age from 2009 to 2016. This data set included 18 academic year cohorts in total, with school absence data for all cohorts. Of these, eight academic year cohorts were old enough to have measures of attainment in the high stakes testing at the end of compulsory schooling (aged 16 years) and six academic year school cohorts could also be followed through into higher education data (Table 1).

Educational Data Sets

The Welsh Government provided annual national administrative school data for all children in Wales for 2009 to 2016. Separate files were provided for high stakes testing at the end of compulsory schooling, referred to as KS4 (Key Stage 4) (ages 15–16 years). The "National Data Collection" data set included attainment data at the end of each of the earlier key stages, KS1 (ages 6–7 years), KS2 (ages 8–11 years), and KS3 (ages 12–14 years). Additional files were provided for school absence data (recorded annually), contextual data including special educational needs, and a household measure of income deprivation. Although the data set included children educated outside of mainstream government schooling, i.e., children attending private schools (2.2%), children attending pupil referral units (0.3%), and children educated at home (0.5%), these students have more limited attainment data, and their contextual data are not recorded centrally and so could not be included in our models alongside data of children from government schools. The Higher Education Statistics Agency (HESA) provided higher education data for the whole of the U.K. from 2009 to 2017.

Diabetes Data Sets

The National Paediatric Diabetes Audit (NPDA) was established in 2003 for comparison of the care and outcomes of all children and young people with all types of diabetes receiving care from pediatric centers in England and Wales (20). Since 2013, this had population coverage of 95–97%. The Brecon Register was established in 1995 and records all childhood-onset diabetes diagnosed in Wales and is known from capture-recapture studies to be 98% complete; this was used as the gold standard for case identification in data linkage. The National Diabetes Audit (NDA) for adults (ages $\geq$16 years) (21) was provided by NHS Digital and is the annual audit of adults with all types of diabetes, beginning in 2003, with data extracted digitally from primary and secondary care sources.

Statistical Analysis

We estimated multilevel models on three outcomes, attainment, absence, and higher education participation. We compared children with type 1 diabetes with the general population, with all individuals in the school cohorts without a diagnosis of diabetes as the reference category,

Table 1—Descriptive statistics for the model samples for each of the three outcomes

	Birth 1993–2010, 18 education cohorts with linked diabetes and school absence data		Birth 1993–2000, 8 education cohorts with linked diabetes and student attainment data		Birth 1993–1998, 6 education cohorts with linked diabetes, school, and higher education data	
	Children without type 1 diabetes	Children with type 1 diabetes	Children without type 1 diabetes	Children with type 1 diabetes	Children without type 1 diabetes	Children with type 1 diabetes
No. of individuals	617,890	2,067	263,426	1,212	217,191	965
Percentage of individuals	99.7	0.3	99.5	0.5	99.6	0.4
No. of person-years	2,605,835	8,776	—	—	—	—
Percentage of person-years	99.7	0.3	—	—	—	—
No. of schools	1,830	1,024	276	229	653	240
No. of females	302,121	998	129,780	566	106,294	448
Percentage of individuals who are female	48.9	48.3	49.3	46.7	48.9	46.4
No. of individuals with SEN	56,458	233	6,954	56	8,986	60
Percentage of person-years	2.2	3.2	2.6	4.6	4.1	6.2
No. of individuals with FSM	471,916	1,271	39,407	203	33,204	157
Percentage of person-years	18.1	18.5	15.0	16.7	15.3	16.3

FSM, free school meals; SEN, Special Educational Needs statement.

excluding the small number of children with other types of diabetes. Children without diabetes comprised the reference group (rather than the lowest HbA_{1c} quintile) to provide a more stable and more easily interpretable basis for comparison. Models assume data were missing at random and unbiased results obtained from complete case analysis. Models of school absence included annual data, so we include prediagnosis person-years alongside person-years for children who were never diagnosed with diabetes in the timeframe of our data. All models were fitted with a combination of iterative generalized least squares and Markov chain Monte Carlo computational procedure as implemented in the MLwiN software, called from Stata with the runmlwin command (22).

Outcome 1: Student Attainment

Student attainment was measured with the high stakes national standardized testing results at the end of compulsory schooling (age 16 years). The measure used was the total grade points score for each subject (grade A* = 58 points, A = 52, B = 46, C = 40, D = 34, E = 28) for the top eight subjects, including English and math. Values were standardized to a mean of zero and SD of 1 within each academic year.

Outcome 2: Higher Education Participation

Information on progression to an undergraduate degree (in a higher education institution anywhere in the U.K.) for children from Welsh schools was obtained from HESA for six cohorts of Welsh school students. We modeled progression directly to higher education at the standard entry point—the year following the completion of further education (age 19 years)—to have consistent results across cohorts.

Outcome 3: School Absence

Student absence was recorded annually. Authorized and unauthorized absences were combined to give a measure of the total number of sessions (half days) missed in an academic year. Where students moved schools in the middle of an academic year the two records for the year could not be easily reconciled, so all student-years containing such moves were excluded from models for this outcome.

Independent Variables

For each of the three outcomes we estimated two models: the first model comparing children with type 1 diabetes versus children without diabetes and the second model comparing children with diabetes grouped into five quintiles of HbA_{1c} versus the children without diabetes reference category. Consideration of all children without diabetes as the reference category in both models provides a clearer illustration of how the distribution of HbA_{1c} effects maps onto the overall binary effect of diabetes. The NPDA and NDA data sets were used to identify children with diabetes, cross-checked against the gold standard diabetes data set, the Brecon Register, followed by further comparison with prevalence estimates in GP records, prescriptions records, and hospital admissions inpatient data. Records of HbA_{1c} were obtained from the NPDA. From 2004 to 2012, the NPDA recorded a single value annually; from 2013, all HbA_{1c} values were recorded (typically three measures per year). For school absence models, we used the mean HbA_{1c} for the academic year; for attainment and higher education, we used the mean HbA_{1c} from the period from diagnosis to the end of compulsory schooling.

Confounding Adjustment

We adjusted for pupil characteristics from the schools contextual data across all models; these included sex, academic cohort, academic year, household deprivation, and special educational needs. Household deprivation is measured with a binary indicator for whether a family is eligible and claiming free school meals, typically for individuals from households with income <£16,190 (~$22,700) or receiving benefits indicative of similar levels of income poverty (23,24). Special educational needs status was recorded as a binary measure for the most severe category of need, since this was the only level that attracts additional funding and direct support. Claiming free school meals was used as a binary indicator of

deprivation. We estimated multilevel models to account for the clustering of students in schools, and in the longitudinal models, the multilevel structure was repeated measures within individuals nested within schools. As a sensitivity analysis, we estimated four separate extensions to the models of attainment: *1*) adjusting for age at diagnosis rather than quintiles of HbA_{1c} to proxy "accumulated exposure" to diabetes, *2*) adjustment for school absence, and *3*) adjustment for prior attainment at age 11 years (KS2) and *4*) contrasting models with no adjustment for socioeconomic status with those including the free school meals indicator of household deprivation and the Welsh Index of Multiple Deprivation measure of neighborhood deprivation. This measure is constructed from weighted indices across eight domains of deprivation (income, education, employment, health, access to services, housing, physical environment, and community safety) (25).

Data and Resource Availability

Patient and Other Consents

Identifiable variables for linkage of health data sets (National Health Service [NHS] number, name, date of birth, postcode, sex) were shared under a Section 251 exemption from the common law duty of confidentiality awarded by the U.K. Health Research Authority Confidentiality Advisory Group. Identifiable variables for linkage of nonhealth data sets (name, date of birth, postcode, sex) were shared separately under the Digital Economy Act 2017 with supporting qualifications agreed with data providers. The data protection legal basis for processing personal data (General Data Protection Regulation and Data Protection Act) was Article 6(1) (e), processing necessary for the performance of a task carried out in the public interest. Probabilistic assignment of the linkage field was performed by NHS Wales Informatics Service, and data linkage and analysis were conducted within the Secure Anonymised Information Linkage (SAIL) platform. Diagrams summarizing the flows and linkages are provided on the project website, along with the fair processing notices and other relevant agreements.

Data Sharing Statement

All individual-level de-identified linked data sets will be made available after the publication of this article alongside the code used to prepare and analyze the data. Data will be available for any research application with direct benefit to health and social care that meets the approval of the data providers and data processors. Data access is subject to *1*) approval through the SAIL Information Governance Review Panel (IGPR) process for access to the data in the SAIL gateway, *2*) approval by data providers, and *3*) approval by the Health Research Authority Confidentiality Advisory Group (HRA CAG); however, the key information governance challenge (the precedent for flowing identifiers for linkage) and technical challenge (data linkage) for creating the data set are made available freely to other researchers. At present, documentation for the data is still limited. There are data dictionaries for the schools data only. We hope to provide fuller documentation during 2023.

Patient and Public Involvement and Dissemination

Public involvement meetings, including adult patients, parents, members of the public, and a range of diabetes practitioners, were used to get feedback on the linkage of confidential patient information without consent, the modeling design, and interpretation of results. Views of child patients were obtained through focus groups with young people and individual meetings with children and their carers after clinic appointments. Findings will be shared with the diabetes community through a lay summary published in the annual NPDA core national report.

RESULTS

Outcome 1: Attainment

Attainment in the high stakes tests at the end of compulsory schooling (aged 16 years) was recorded for 263,426 individuals without diabetes and 1,212 individuals who were diagnosed with type 1 diabetes prior to completion of compulsory schooling (Table 1). Figure 1 shows attainment by whether a child had diabetes and HbA_{1c} quintiles. No difference in the standardized points score was seen between children with and without diabetes (0.001 SD, 95% CI −0.047 to 0.049, $P < 0.957$). Compared with children without diabetes, children in the most optimal (lowest) HbA_{1c} quintile (HbA_{1c} Q1) had 0.267 SD (0.160–0.374, $P < 0.001$) higher attainment, whereas children in the least optimal (highest) HbA_{1c} quintile (HbA_{1c} Q5) had −0.395 SD (−0.504 to −0.287, $P < 0.001$) lower attainment. To aid interpretation, we also considered estimates for the same models using the unstandardized raw points totals for the outcome. On the basis of those raw scores, the children without diabetes have predicted attainment of 297.9 points (e.g., 4× C grades, 4× D grades), whereas those in the most optimal HbA_{1c} quintile have predicted 321.3 points (e.g., 8× C grades) and the least optimal HbA_{1c} quintile 263.1 (e.g., 7× D grades, 1× E grade).

Outcome 2: Higher (College) Education Participation

For modeling entry to higher education, we had data from six complete cohorts of school students including 217,191 children without diabetes and 965 children who were diagnosed with type 1 diabetes prior to completion of compulsory schooling. Figure 2 shows progression to higher education by whether a child had diabetes and HbA_{1c} quintiles. Progression to higher education was not different between children with or without diabetes (odds ratio 1.067, 95% CI 0.919–1.239, $P < 0.393$), equivalent to predicted rates of progression to higher education of 23.5% for children with diabetes compared with 22.4% for children without diabetes. Compared with children without diabetes, children in the most optimal HbA_{1c} quintiles were 1.703 (1.257–2.307, $P < 0.001$) times more likely to attend higher education and in the least optimal HbA_{1c} quintiles 0.412 (0.258–0.656, $P < 0.001$) times as likely to attend higher education, equivalent to predicted progression rates of 33.0% in the most optimal HbA_{1c} quintile vs. 10.6% in the least optimal.

Outcome 3: School Absence

School absence was recorded for 18 cohorts of students, including 617,890 individuals without diabetes with 2,605,835 person-years of school attendance and 2,067 individuals diagnosed with type 1 diabetes prior to completion of compulsory schooling, with 1,902 person-years prior to diagnosis and 6,874 person-years after diagnosis (Table 1). Figure 3 shows school absence by whether a child had diabetes and HbA_{1c} quintiles. Children with diabetes were absent for 8.8 (95% CI 8.045–9.463, $P < 0.001$) more sessions than children without diabetes. Children in the most optimal HbA_{1c} quintiles missed

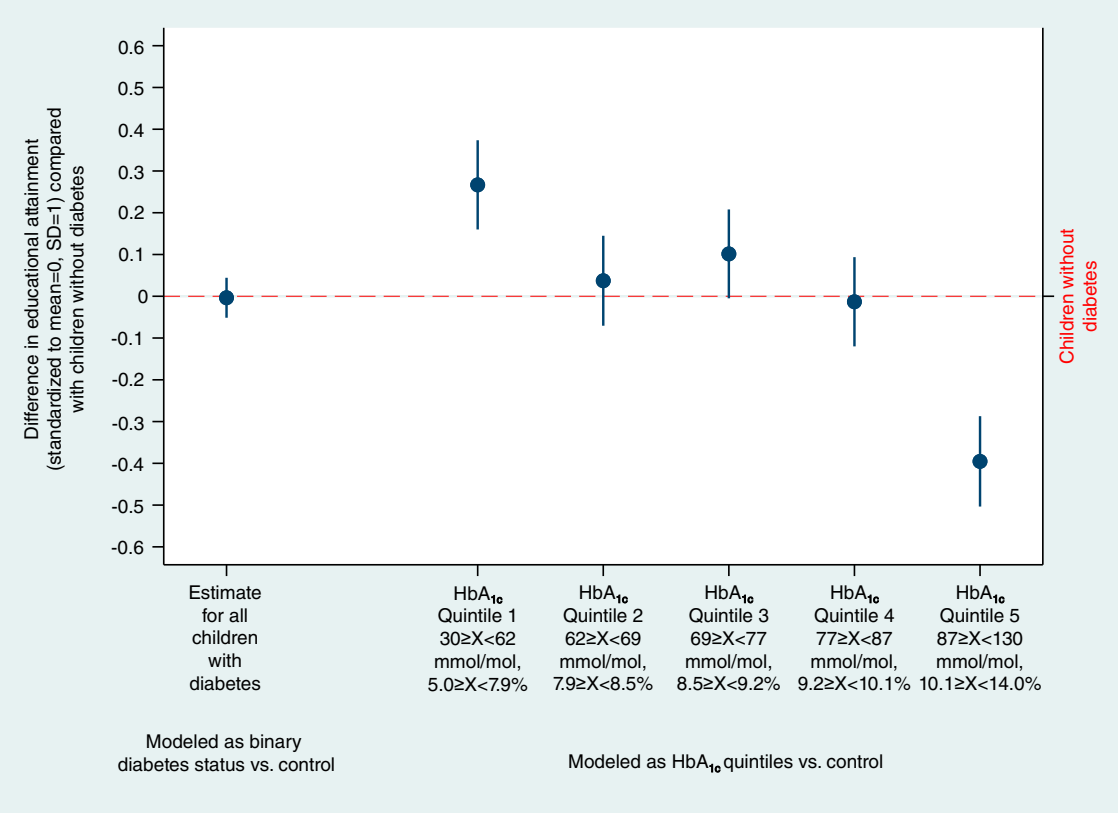

Figure 1—Conditional models of standardized educational attainment score by whether a child has type 1 diabetes (binary and HbA_{1c} quintiles).

6.7 (5.563–7.842, $P < 0.001$) more sessions per year, whereas children in the least optimal HbA_{1c} quintiles missed 14.8 (13.532–15.998, $P < 0.001$) more sessions per year, than children without diabetes. Children with diabetes could miss up to six sessions per year due to routine diabetes-related health appointments; however, it is unlikely that all routine appointments would fall on school days or that children attend all the appointments they should. We estimate that the average student would miss between two to three sessions per year due to routine diabetes-related appointments, and so even for the most optimally managed children with diabetes, there is substantial excess absence over and above that accounted for by routine appointments. Some of that excess absence is due to unauthorized absence, accounting for 8% of absence in the most optimal three HbA_{1c} quintiles, rising to 18% in the least optimal HbA_{1c} quintile.

Sensitivity Analysis

Figure 4 shows that the age (schooling period) in which a child is diagnosed with type 1 diabetes appears to make no difference to their final attainment at age 16 years. Supplementary Fig. 1 shows that after adjustment for school absence, children with diabetes have better overall attainment than children without diabetes (0.076 SD, 95% CI 0.032–0.120, $P < 0.001$), and the association with HbA_{1c} quintile is attenuated but still present (0.258 SD, 0.160–0.355, $P < 0.001$, in the most optimal HbA_{1c} quintile and −0.182 SD, 0.281 to −0.083, $P < 0.001$, in the least optimal quintile). Supplementary Fig. 2 shows that adjustment for prior attainment leads to a marginally significant negative difference in progress for children diagnosed with diabetes in secondary school compared with those without diabetes (−0.088 SD, −0.176 to <0.001, $P < 0.050$). For the models with HbA_{1c} quintiles rather than binary diabetes status, however, we see a substantial change after adjustment for prior attainment, with an attenuation of 69% of the estimate for the most optimal quintile and 37% for the least optimal quintile, although the pattern of decreasing attainment by HbA_{1c} quintiles remains.

Supplementary Fig. 3 shows the extent to which family socioeconomic measures account for both educational outcomes and HbA_{1c} levels. We estimated a variation on the model of age 16 years attainment by HbA_{1c} quintiles, firstly including no measures of socioeconomic status and then a second model that includes household socioeconomic status (eligible and claiming free school meals) and an additional neighborhood measure of deprivation, the Welsh Index of Multiple Deprivation. In the model without adjustment for socioeconomic status, the HbA_{1c} quintiles estimates range from −0.478 ($P < 0.001$) for the least optimal HbA_{1c} quintile to 0.293 ($P < 0.001$) for the most optimal HbA_{1c} quintile. When we adjust for both measures of socioeconomic status, the estimates for HbA_{1c} quintiles range from −0.390 ($P < 0.001$) for the least optimal HbA_{1c} to 0.258 ($P < 0.001$) for the most optimal HbA_{1c}. Overall, adjustment for socioeconomic status attenuates the HbA_{1c} effects by 18% for the least optimal HbA_{1c} quintile. In addition, we observe that for children living in the most deprived households, only 11% had mean HbA_{1c} levels in the most optimal quintile, with 37% having HbA_{1c} levels in the least optimal quintile.

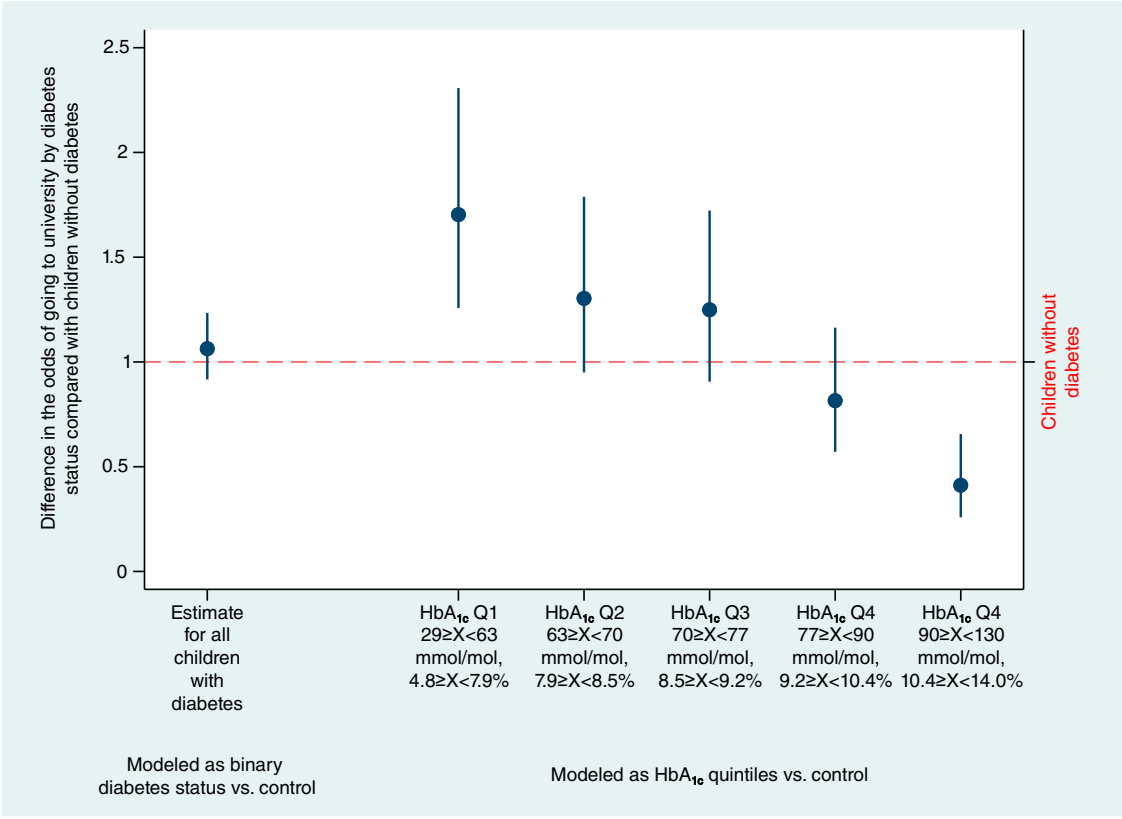

Figure 2—Conditional models of progression to higher education by whether a child has type 1 diabetes (binary and HbA_{1c} quintiles).

CONCLUSIONS

Key Findings

Our data indicate that in a national population of young people diagnosed with type 1 diabetes before the end of compulsory schooling, compared with the remainder of their contemporaries, having diabetes was not associated with any difference in high stakes exam attainment at age 16 years (Fig. 1), despite a mean of 8.8 additional school sessions missed annually (Fig. 3). Indeed, after adjustment for school absence, children with diabetes overall actually had better attainment than children without diabetes (Supplementary Fig. 1). Moreover, the odds of young people progressing to higher education were also no different between people with and without diabetes (Fig. 2). Importantly, duration of diabetes was also not associated with reduced academic performance (Fig. 4).

By contrast, breaking down the type 1 diabetes cohort by mean HbA_{1c} levels attained between diagnosis and the end of compulsory schooling revealed major differences with children without diabetes (Fig. 1). Attainment at age 16 years of children in the most optimal HbA_{1c} quintile was over one-quarter of an SD (4 grades) higher than that of their peers without diabetes, whereas the attainment in the least optimal quintile was almost two-fifths of an SD (5 grades) lower. The value of an additional grade (e.g., moving from 8 grade Bs across the top 8 subjects to 7 grade Bs and 1 grade A) in undiscounted earnings over the working lifetime is estimated to be £23,000 (~$31,500), equivalent to three-quarters of the average full-time annual salary in the U.K. in 2019 (26).

Furthermore, the pattern of attainment according to HbA_{1c} quintile was replicated on higher education entry (Fig. 2), with the most optimal HbA_{1c} quintile group exceeding the achievement of the general population, being 1.7 times more likely to attend higher education, whereas the least optimal HbA_{1c} quintile group was 0.4 times as likely to attend higher education. In other words, those in the most optimal HbA_{1c} quintile were almost threefold more likely to attend higher education than those in the least optimal HbA_{1c} quintile, with predicted probabilities of 33.0% vs. 10.6% (with use of reference values for independent variables).

These findings are consistent with those of Fleming et al. (27) and previous publications in this area. However, we substantially extend these earlier observations by using robust high stakes examinations as outcomes and replicating these findings at college entry, an important stage in impact for the future. In addition, in categorizing children without diabetes as the reference group, our models emphasize that the gradient in attainment by HbA_{1c} levels arises from both overperformance and underperformance. In other words, those in the most optimal HbA_{1c} quintile appears to overachieve compared with the general population, whereas those in the least optimal HbA_{1c} quintile very substantially underachieve.

The overachievement of children in the lowest HbA_{1c} quintile compared with their peers without diabetes seems unlikely to be explained by a "beneficial" effect of diabetes and raises the possibility that the marked gradient in educational achievement by HbA_{1c} is due to factors unrelated to glucose levels, such

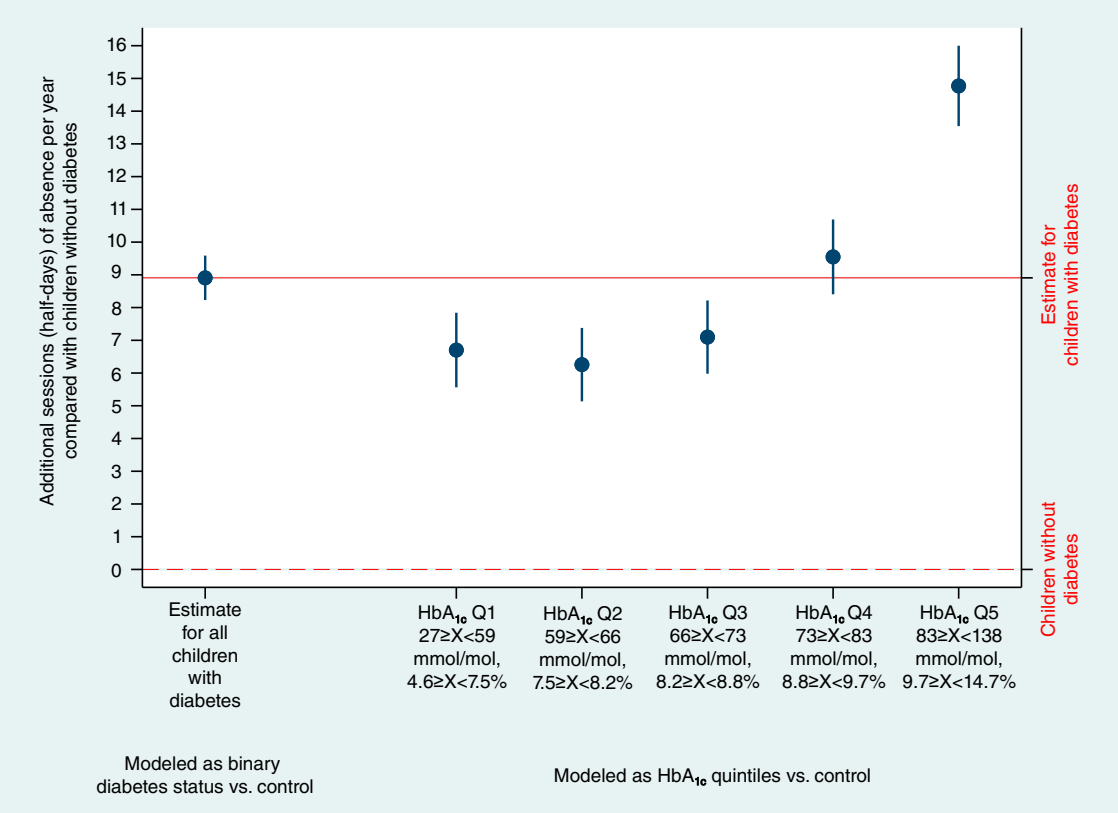

Figure 3—Conditional models of school absence by whether a child has type 1 diabetes (binary and HbA_{1c} quintiles).

as socioeconomic and familial factors (28). Consistent with these observations, the age (schooling period) in which a child is diagnosed with diabetes, and hence the amount of "exposure" to diabetes accrued before testing, made no difference to final attainment at age 16 years (Fig. 4). In addition, a marked gradient in HbA_{1c} by deprivation was observed in our data, with children living in the most deprived households more than three times more likely to have an HbA_{1c} in the highest quintile compared with the lowest HbA_{1c} quintile. When we adjusted for socioeconomic status in our analysis, we saw an 18% improvement in the achievement of children in the highest HbA_{1c} quintile. Skipper et al. (13) observed a substantially greater attenuation of the HbA_{1c} gradient in attainment after adjustment. However, our socioeconomic adjustments did not include the family factors used by Skipper et al., which included elements such as parental educational attainment (a proxy for parental IQ), single-parent families, and immigrant status and which resulted in even greater attenuation of the gradient by HbA_{1c} in their analysis than we observed (13). To account for this, in contrast to previous analyses, we were able to adjust for prior educational attainment for those diagnosed aged 11–16 years. This allows for identification of any change in an individual child's educational trajectory before and after diagnosis. Because factors like parental intelligence and social status are relatively stable over time, a change in educational trajectory following the diagnosis of diabetes is less likely to be the result of socioeconomic factors influencing educational attainment, and an approximate upper bound on the direct (biological) diabetes factors. Following this adjustment, we see attenuation of 69% of the estimate for the most optimal quintile and 37% for the least optimal quintile (Supplementary Fig. 2), consistent with a major effect for family factors. Adjustment for school absence rates (more than twice as high in the highest HbA_{1c} quintile) also attenuated the effect of HbA_{1c} quintile (Supplementary Fig. 1), although this could include absence related to glucose-related ill health in addition to socioeconomic factors.

Taken together, the results of our sensitivity analyses suggest that there may be socioeconomic and family factors that are associated with both high HbA_{1c} and poor educational attainment. However, they do not exclude a direct effect on high or low glucose levels on cognitive function as a contributory factor, as even after all our adjustments, a gradient of achievement by HbA_{1c} quintile remained, although substantially attenuated. In addition, after adjustment for educational trajectory before diagnosis of diabetes (prior attainment), children with diabetes overall did show a small reduction of educational attainment of 0.08 SD compared with the children without diabetes (Supplementary Fig. 2).

Strengths and Weaknesses of the Study

Strengths of our study include the robust nationwide population with type 1 diabetes studied, defined using national audit data validated with a national register; the high-quality attainment outcome, summarizing standardized attainment across the top eight subjects in the high stakes assessment at the end of compulsory schooling; and the large sample size, both cross-sectionally and in terms of the number of academic-year cohorts. In

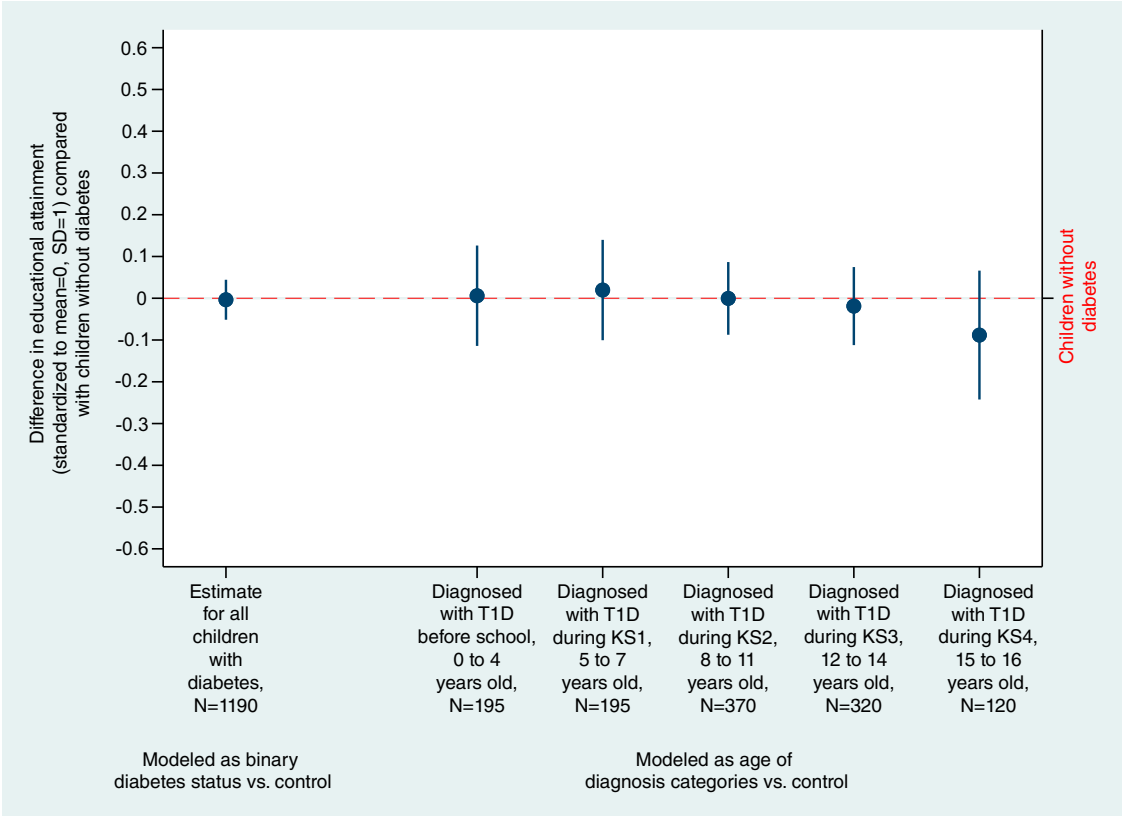

Figure 4—Sensitivity analysis showing models of standardized student attainment by binary type 1 diabetes status and the type 1 diabetes sample broken down by age of diagnosis rather than HbA_{1c} quintile.

particular, our study includes use of high stakes examinations, with replication for university admissions, both key determinations of an individual's future economic performance and prosperity. In addition, we were able to use an individual's age of onset of diabetes and multiple high stakes tests throughout school, enabling us to also explore the impact of "time at risk" from diabetes. A potential weakness of our study is that we average each individual's HbA_{1c} measures over a year (for school absence models) or the whole school life course since diagnosis (for attainment and progression to university measures). This "averaging out" will mask periods of high HbA_{1c}, particularly where those periods were short, even though they may have potentially large impacts on education, health, and other outcomes. Further, because this study includes administrative data, we are limited in the variables available as contextual factors. Most importantly, there are likely to be omitted variables, such as levels of parental support, that are correlated with HbA_{1c} levels and educational outcomes. Finally, the time period for our study (from 2009–2016) includes many changes in treatment, including more stringent glycemic targets, more intensive insulin regimens, insulin pumps, and continuous glucose monitoring. These changes may account both for some of the differences in educational outcomes between individuals (which may be further correlated with socioeconomic status) and for differences between our findings and estimates from other studies using earlier cohorts. In addition, we only have complete contextual and attainment data for the children who attend mainstream government schooling (97%) and so are not able to comment on the 3% who are educated at private schools, at home, or in other modes, including pupil referral units.

Our article substantially advances the literature by resolving the controversy over whether there is any overall negative effect of diabetes on education as we both included high stakes testing and replicated further with inclusion of university admission. We also used repeated assessments over time, enabling us to explore the impact of longer duration of disease. It is reassuring that neither diabetes status nor duration of diabetes was associated with adverse educational outcomes.

Implications

We believe that our analysis of the comparison between children with type 1 diabetes and their peers without diabetes has important implications for interpretation. Fleming et al. (27) concluded that "children with type 1 diabetes fare worse than their peers in respect of education and health outcomes," and previous publications refer to effects of type 1 diabetes across many cognitive domains. Our data strongly indicate that there is no overall negative effect of diabetes on educational performance, even for those with a longer duration of diabetes. Furthermore, an effect of blood glucose concentrations on cognition is not consistent with the apparent "overperformance" of children with more optimal HbA_{1c} levels that we report or the very small or insignificant differences in overall attainment of children with diabetes that are a consistent finding in our data and other well-matched cohorts (18,19,27). Indeed

the lack of difference in attainment in the population of children with diabetes overall is all the more remarkable given that they miss one-third more school sessions, and we have previously shown that they have a persistent excess of hospital admissions (1).

We believe our findings have several important implications for improving outcomes for children with type 1 diabetes and other chronic diseases. Firstly, health care professionals can reassure parents that (on average) a diagnosis of diabetes or its duration should not substantially affect the learning of the child (29). Secondly, our data raise the possibility that intensified glycemic management per se will have a limited effect on improving educational outcomes in those with the least optimal HbA_{1c}. Rather, less optimal HbA_{1c} levels identify children for whom more intensive educational and clinical support should be considered. Furthermore, our data suggest that those more likely to experience earlier onset of long-term complications of diabetes due to greater glycemic exposure are also more likely to have low educational attainment. This "double jeopardy" would be expected to have a major adverse socioeconomic impact with lower earnings potential compounded by long-term sickness and disability. Thus, efforts to improve glycemic management as well as to delay or prevent the onset of diabetes (30), especially in those most likely to have less optimal diabetes management, may help reduce the additional burden of early-onset diabetes-related complications on top of the consequences of lower educational attainment or, at least, delay these until individuals are more financially secure.

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