International comparison of glycaemic control in people with type 1 diabetes: an update and extension

Article *in* Diabetic Medicine · December 2021

DOI: 10.1111/dme.14766

CITATIONS
34

READS
2,073

62 authors, including:

Regina Prigge
The University of Edinburgh
15 PUBLICATIONS **111** CITATIONS
SEE PROFILE

Aveni Haynes
Telethon Kids Institute / Life for a Child
57 PUBLICATIONS **1,019** CITATIONS
SEE PROFILE

Elizabeth A Davis
University of Western Australia
332 PUBLICATIONS **11,415** CITATIONS
SEE PROFILE

Birgit Rami-Merhar
Medical University of Vienna
207 PUBLICATIONS **4,674** CITATIONS
SEE PROFILE

Received: 11 May 2021 | Accepted: 27 November 2021

DOI: 10.1111/dme.14766

DIABETIC Medicine

RESEARCH ARTICLE

International comparison of glycaemic control in people with type 1 diabetes: an update and extension

Regina Prigge[1] | **John A. McKnight**[1,2] | **Sarah H. Wild**[1] | **Aveni Haynes**[3] | **Timothy W. Jones**[3,4,5] | **Elizabeth A. Davis**[3,4,5] | **Birgit Rami-Merhar**[6] | **Maria Fritsch**[6,7] | **Christine Prchla**[8] | **Astrid Lavens**[9] | **Kris Doggen**[9] | **Suchsia Chao**[9] | **Ronnie Aronson**[10] | **Ruth Brown**[10] | **Else H. Ibfelt**[11] | **Jannet Svensson**[12] | **Robert Young**[13] | **Justin T. Warner**[14] | **Holy Robinson**[15] | **Tiina Laatikainen**[16,17,18] | **Päivi Rautiainen**[18] | **Brigitte Delemer**[19] | **Pierre François Souchon**[20] | **Alpha M. Diallo**[19] | **Reinhard W. Holl**[21,22] | **Sebastian M. Schmid**[22,23] | **Klemens Raile**[24] | **Stelios Tigas**[25] | **Alexandra Bargiota**[26] | **Ioanna Zografou**[27] | **Andrea O. Y. Luk**[28] | **Juliana C. N. Chan**[29] | **Sean F. Dinneen**[30,31] | **Claire M. Buckley**[32] | **Oratile Kgosidialwa**[30] | **Valentino Cherubini**[33] | **Rosaria Gesuita**[34] | **Ieva Strele**[35] | **Santa Pildava**[36] | **Henk Veeze**[37] | **Henk-Jan Aanstoot**[37] | **Dick Mul**[37] | **Craig Jefferies**[38] | **John G. Cooper**[39] | **Karianne Fjeld Løvaas**[39] | **Tadej Battelino**[40,41] | **Klemen Dovc**[40,41] | **Nataša Bratina**[40,41] | **Katarina Eeg-Olofsson**[42,43] | **Ann-Marie Svensson**[43,44] | **Soffia Gudbjornsdottir**[43,44] | **Evgenia Globa**[45] | **Nataliya Zelinska**[45]

[1]Usher Institute, University of Edinburgh, Edinburgh, UK

[2]Metabolic Unit and Acute Receiving Unit, Western General Hospital, Edinburgh, UK

[3]Telethon Kids Institute, The University of Western Australia, Perth, Australia

[4]Department of Endocrinology and Diabetes, Perth Children's Hospital, Perth, Australia

[5]School of Paediatrics and Child Health, The University of Western Australia, Perth, Australia

[6]Department of Paediatrics and Adolescent Medicine, Medical University of Vienna, Vienna, Austria

[7]Department of Paediatrics and Adolescent Medicine, Medical University of Graz, Graz, Austria

[8]Klinik Donaustadt, Department of Paediatrics and Adolescent Medicine, Vienna, Austria

[9]Sciensano, Brussels, Belgium

[10]LMC Diabetes & Endocrinology, Toronto, Canada

[11]Steno Diabetes Center Copenhagen, Gentofte, Denmark

[12]Department of Paediatrics, Copenhagen University Hospital Herlev, Copenhagen, Denmark

[13]Diabetes UK, London, UK

[14]Children's Hospital for Wales, Cardiff, UK

[15]Royal College of Paediatrics and Child Health, London, UK

[16]Institute of Public Health and Clinical Nutrition, University of Eastern Finland, Kuopio, Finland

[17]National Institute for Health and Welfare, Helsinki, Uusimaa, Finland

J. A. McKnight and S. H. Wild are joint senior authors.

[18]Joint municipal authority for North Karelia social and health services (Siunsote), Joensuu, Finland

[19]Department of Endocrinology, Diabetes and Nutrition, American Memorial Hospital, University Hospital of Reims, Reims, France

[20]Department of Paediatrics, American Memorial Hospital, University Hospital of Reims, Reims, France

[21]Institute of Epidemiology and Medical Biometry, ZIBMT, University of Ulm, Ulm, Germany

[22]German Centre for Diabetes Research (DZD), Neuherberg, Germany

[23]Institute for Endocrinology and Diabetes, University of Lübeck, Lübeck, Germany

[24]Department of Paediatric Endocrinology and Diabetology, University Medicine Berlin, Charité, Berlin, Germany

[25]Department of Endocrinology, University of Ioannina, Ioannina, Greece

[26]Department of Endocrinology and Metabolic Diseases, University of Thessaly, Volos, Greece

[27]Second Propaedeutic Department of Internal Medicine, Aristotle University of Thessaloniki, Hippokratio General Hospital, Thessaloniki, Greece

[28]Department of Medicine & Therapeutics, The Chinese University of Hong Kong, Hong Kong Institute of Diabetes and Obesity, Hong Kong, China

[29]The Chinese University of Hong Kong, Li Ka Shing Institute of Health Science, Hong Kong, China

[30]Centre for Diabetes, Endocrinology and Metabolism, Galway University Hospital, Galway, Ireland

[31]NUI Galway, Galway, Ireland

[32]School of Public Health, University College Cork, Cork, Ireland

[33]Department of Women's and Children's Health, Salesi Hospital, Ancona, Italy

[34]Centre of Epidemiology and Biostatistics, Polytechnic University of Marche, Ancona, Italy, Italy

[35]Department of Public Health and Epidemiology, Riga Stradins University, Riga, Latvia

[36]The Centre for Disease Prevention and Control of Latvia, Riga, Latvia

[37]Diabeter, National Centre for Paediatric and Adolescent Diabetes, Rotterdam, the Netherlands

[38]Department of Endocrinology, Starship Children's Health, Auckland, New Zealand

[39]Norwegian Diabetes Register for Adults, Norwegian Organization for Quality Improvement of Laboratory Examinations (Noklus), Haraldsplass Deaconess Hospital, Bergen, Norway

[40]Department of Paediatric Endocrinology, Diabetes and Metabolic Diseases, UMC – University Children's Hospital, University Medical Centre Ljubljana, Ljubljana, Slovenia

[41]Faculty of Medicine, University of Ljubljana, Ljubljana, Slovenia

[42]Department of Medicine, Sahlgrenska University Hospital, University of Gothenburg, Gothenburg, Sweden

[43]Department of Molecular and Clinical Medicine, Institute of Medicine, University of Gothenburg, Sahlgrenska Academy, Gothenburg, Sweden

[44]Centre of Registers in Region VästraGötaland, Göteborg, Sweden

[45]Ukrainian Research Centre of Endocrine Surgery, Endocrine Organs and Tissue Transplantation, MoH of Ukraine, Kyiv, Ukraine

Correspondence
Sarah H Wild, Usher Institute, University of Edinburgh, Edinburgh, UK.
Email: Sarah.Wild@ed.ac.uk

Funding information

This work has had local funding support for registries, but there was no specific funding for the collaboration.

Abstract

Aims: To update and extend a previous cross-sectional international comparison of glycaemic control in people with type 1 diabetes.

Methods: Data were obtained for 520,392 children and adults with type 1 diabetes from 17 population and five clinic-based data sources in countries or regions between 2016 and 2020. Median HbA_{1c}(IQR) and proportions of individuals with HbA_{1c} < 58 mmol/mol (<7.5%), 58–74 mmol/mol (7.5–8.9%) and ≥75 mmol/mol (≥9.0%) were compared between populations for individuals aged <15, 15–24 and ≥25 years. Logistic regression was used to estimate the odds ratio (OR) of HbA_{1c} < 58 mmol/mol (<7.5%) relative to ≥58 mmol/mol (≥7.5%), stratified and adjusted for sex, age and data source. Where possible, changes in the proportion of individuals in each HbA_{1c} category compared to previous estimates were calculated.

Results: Median HbA_{1c} varied from 55 to 79 mmol/mol (7.2 to 9.4%) across data sources and age groups so a pooled estimate was deemed inappropriate. OR (95% CI) for HbA_{1c}< 58 mmol/mol (<7.5%) were 0.91 (0.90–0.92) for women

compared to men, 1.68 (1.65–1.71) for people aged <15 years and 0.81 (0.79–0.82) aged15–24 years compared to those aged ≥25 years. Differences between populations persisted after adjusting for sex, age and data source. In general, compared to our previous analysis, the proportion of people with an HbA_{1c} < 58 mmol/l (<7.5%) increased and proportions of people with HbA_{1c}≥ 75 mmol/mol (≥9.0%) decreased.

Conclusions: Glycaemic control of type 1 diabetes continues to vary substantially between age groups and data sources. While some improvement over time has been observed, glycaemic control remains sub-optimal for most people with Type 1 diabetes.

KEYWORDS

glycaemic control, HbA_{1c}, registers of people with diabetes, type 1 diabetes

1 | INTRODUCTION

It is widely recognized that lower HbA_{1c} in people with type 1 diabetes reduces the risk of microvascular and macrovascular complications.[1] During the last ten years international guidelines have recommended a target HbA_{1c} of 48–58 mmol/mol (6.5–7.5%) for most people with type 1 diabetes, allowing for clinical judgement to relax these targets for people with severe hypoglycaemia, short life expectancy, severe comorbidity or complications.[2–4] The current International Society of Pediatric and Adolescent Diabetes (ISPAD) and American Diabetes Association (ADA) guidelines recommend HbA_{1c}targets of <53 mmol/mol (<7.0%) for children/adolescents and most non-pregnant adults and a target of <48 mmol/mol (<6.5%) for other adults, if it can be safely achieved without significant hypoglycaemia.[5,6] Less stringent goals are recognized to be appropriate for people with a history of severe hypoglycaemia, severe co-morbidities or limited life expectancy. The changes in recommended glycaemic targets for people with type 1 diabetes relate in part to evidence of cardiovascular risk reduction from lower targets[7] and also to the availability of new technologies of glucose monitoring, the increasing use of continuous subcutaneous insulin infusion (CSII also known as pump) therapy and their combination.

Type 1 diabetes is a condition which is difficult to manage with current therapies and recommended glycaemic targets are often not achieved. We have previously investigated how well these targets are achieved by analyzing HbA_{1c} data from 324,501 people with type 1 diabetes with information derived from population or clinic-based registers from 19 countries or regions.[8] The results revealed substantial variation in glycaemic control among people with type 1 diabetes and room for significant improvement, particularly in young adults. A recent publication describing this pattern among children has also noted significant variation.[9] The HbA_{1c} data in our previous publication were mostly from the years 2010 to 2012. Since then, there has been increasing use of insulin analogues and test strips, improved education and psychological support for patients in some regions and increasing use of the new technologies such as CSII and glucose sensor technology including flash/intermittent glucose monitoring (is-CGM) or continuous/real time glucose monitoring systems (rt-CGM).[10] Our hypothesis is that the sum of these changes will have had a significant impact on HbA_{1c} in the wider population with type 1 diabetes. To the best of our knowledge, this hypothesis has not been tested within and across all age groups across countries/regions.

We therefore set up a further collaboration with colleagues who have access to relevant data to reassess current patterns of glycaemic control in children and adults with type 1 diabetes.

What's new

- Glycaemic control continues to vary widely within and between countries
- There have been many advances in the treatment of diabetes in recent years
- In general glycaemic control has improved over time, particularly among children and adolescents but marked variation in patterns of glycaemic control among people with type 1 diabetes remains
- Reducing variation between settings requires a better understanding of the complex factors affecting management of type 1 diabetes including health care systems and their interaction with patients and families

Our aim was to update and extend the previous international comparison of glycaemic control in people with type 1 diabetes, and to describe the change in HbA_{1c} profiles in those countries that had contributed to our previous analysis.

2 | METHODS

2.1 | Data source

All collaborators were asked to supply descriptive data and counts of patients within HbA_{1c} categories for the updated analysis of their most recently available data between 2016 and 2020, by sex, age at date of HbA1c measurement, and, where available, diabetes duration and CSII use. In addition, they were asked to provide median HbA_{1c} values for their population over the time period of data included, separately for children aged <15 years, young adults aged 15–24 years, and adults aged ≥25 years. These age groups were chosen to provide data for children, adolescents/young adults and older adults and to be consistent with our previous study.

We received data from collaborators in 22 different countries. We characterized the datasets as 'national' if they were deemed by the local clinical and data analyst team, to be representative of the population of the country of origin, 'regional' if they were representative of the population within a region, or regions, and 'clinic' if they were from a single or group of clinics that might not represent the breadth of the regional or national population with type 1 diabetes. Details for each data source are given in the supplementary material as Supplementary Text: narrative description of data sources.

2.2 | Statistical analyses

2.2.1 | Descriptive statistics

We performed analyses using R version 3.6.2. Median HbA_{1c} (IQR), sex, CSII use, duration of type 1 diabetes, and the proportions of individuals with no measurement of HbA_{1c} during the study period were compared between data sources in three age groups (<15 years, 15–24 years, ≥25 years). In keeping with our previous report, proportions of individuals with HbA_{1c} < 58 mmol/mol (<7.5%), 58–74 mmol/mol (7.5–8.9%) and ≥75 mmol/mol (≥9.0%) were compared between data type of source (national or regional population-based vs. clinic-based) in each of the three age groups. Furthermore, we compared the proportion of people in each HbA_{1c} category by age and sex, and we investigated the proportion of people using CSII in each HbA_{1c} category by data source. To incorporate the latest 2020 American Diabetes Association guideline,[5] we additionally show the proportions of people meeting the new HbA_{1c} targets of <53 mmol/mol (<7.0%) and <48 mmol/mol (<6.5%) in each of the three age groups by countries and data sources where data were available.

2.2.2 | Logistic regression analysis

Logistic regression was used to estimate the odds of HbA_{1c} < 58 mmol/mol (<7.5%) relative to HbA_{1c} ≥ 58 mmol/mol (≥7.5%) using a complete case analysis (that is exclusion of missing data). The first model was adjusted for sex, age and type of data source. In order to further investigate differences between countries, the second and third model was stratified by type of data source and adjusted for country/region of origin. We used the largest sub-groups as the comparison groups. Data from each source were included in each analysis where information was available for more than 100 people in each age group to reduce variability due to small numbers.

2.2.3 | Comparison over time

Using data from the subset of countries that contributed data to this analysis and the same methods and data sources as the previous international comparison,[8] we investigated the change in HbA_{1c} profiles by calculating the absolute and relative change in the proportion of individuals with HbA_{1c} < 58 mmol/mol (<7.5%), 58–74 mmol/mol (7.5–8.9%) and ≥75 mmol/mol (≥9.0%). New Zealand and Ukraine contributed data to both analyses but, as different data sources or populations were used or included for the two periods, time comparisons were not performed. For consistency with the previous analysis,[8] data from England and Wales were combined for individuals aged 15–24 and ≥25 years in the time comparison analysis.

2.3 | Ethics statement

Contributors obtained the appropriate approvals for contributing to this collaboration for their jurisdiction. The nature of the study using anonymised and/or aggregated data in the form of clinical audit means that individual consent and formal ethical approval is not required.

3 | RESULTS

3.1 | Study population

Data were obtained from 520,392 children and adults with type 1 diabetes from 17 national or regional

TABLE 1 Characteristics of populations of people with type 1 diabetes by country for each of the three age groups presented in decreasing population size for national, regional and clinic-based data sources

Country or region	Data source	N	Male (%)[a]	Median HbA_{1c} mmol/mol (IQR)	HbA_{1c} % (IQR)	Missing HbA_{1c} (%)[a]	Diabetes duration ≥5 years (%)[a]	CSII use (%)[a]
< 15 years								
England	National	18,514	51.4	60 (54; 68)	7.7 (7.0; 8.3)	6.1	–	38.8
Germany	National	17,463	52.1	58 (51; 67)	7.5 (6.8; 8.3)	1.3	–	59.3
Ukraine	National	6618	51.4	67 (56; 83)	8.3 (7.3; 9.7)	13.3	32.0	2.2
Belgium	National	2242	51.9	56 (50; 63)	7.3 (6.7; 7.9)	1.0	36.6	24.6
Scotland	National	1960	51.7	62 (56; 69)	7.8 (7.3; 8.5)	2.2	35.6	46.4
Denmark	National	1869	52.6	57 (50; 64)	7.4 (6.7; 8.0)	15.5	28.5	71.3
Austria	National	1444	54.4	57 (50; 64)	7.4 (6.8; 8.1)	0.6	–	63.8
Wales	National	1,045	48.3	60 (52; 68)	7.7 (7.0; 8.4)	5.6	–	37.8
Latvia	National	396	46.5	76 (62; 95)	9.1 (7.8; 10.8)	12.1	36.4	–
Slovenia	National	382	48.4	58 (53; 65)	7.5 (7.0; 8.1)	0.0	36.6	74.8
Hong Kong	National	228	38.2	65 (56; 75)	8.1 (7.3; 9.0)	8.3	39.5	–
Australia	Regional	627	51.7	60 (52; 66)	7.6 (6.9; 8.2)	3.5	38.0	48.0
New Zealand	Regional	324	47.2	67 (57; 81)	8.3 (7.4; 9.6)	8.8	42.8	22.5
Italy	Regional	192	55.7	55 (51; 65)	7.2 (6.8; 8.1)	0.0	36.5	37.0
Finland	Regional	131	64.1	62 (56; 68)	7.8 (7.3; 8.4)	2.3	–	–
France	Regional	40	55.0	64 (58; 69)	8.0 (7.5; 8.5)	0.0	75.0	2.6
Netherlands	Clinic	583	50.6	57 (52; 65)	7.4 (6.9; 8.1)	2.2	43.1	66.0
Ireland	Clinic	74	43.2	68 (58; 78)	8.4 (7.5; 9.2)	12.2	38.9	31.1
Greece	Clinic	26	46.2	55 (51; 60)	7.2 (6.8; 7.6)	3.8	50.0	15.4
15–24 years								
England	National	43,115	53.5	72 (60; 88)	8.7 (7.6; 10.2)	18.7	69.1	11.2
Germany	National	10,823	54.1	62 (53; 74)	7.8 (7.0; 8.9)	1.8	–	42.4
Wales	National	5995	53.4	73 (61; 88)	8.8 (7.7; 10.2)	20.6	69.1	11.2
Sweden[b]	National	5175	55.9	58 (50; 70)	7.5 (6.7; 8.6)	2.4	82.1	40.6
Belgium	National	4692	53.3	60 (52; 69)	7.6 (6.9; 8.5)	2.2	71.5	12.8
Scotland	National	4237	52.1	71 (60; 86)	8.6 (7.6; 10.0)	9.0	77.0	24.0
Ukraine[c]	National	2665	52.5	72 (61; 88)	8.7 (7.7; 10.2)	10.0	62.8	1.0
Norway[b]	National	1632	56.1	66 (55; 77)	8.2 (7.2; 9.2)	2.1	78.8	52.9
Latvia	National	529	54.6	79 (64; 99)	9.4 (8.0; 11.2)	21.9	74.5	–
Hong Kong	National	410	46.1	64 (54; 77)	8.0 (7.0; 9.2)	16.3	70.7	–
Slovenia	National	355	54.9	61 (53; 70)	7.7 (7.0; 8.6)	0.8	76.9	74.6
Australia[d]	Regional	484	50.2	64 (55; 78)	8.0 (7.2; 9.3)	1.9	73.6	48.1
Italy	Regional	324	50.6	60 (53; 69)	7.6 (7.0; 8.5)	1.2	76.5	26.5
Finland	Regional	177	53.1	68 (59; 76)	8.3 (7.5; 9.1)	4.5	–	–
New Zealand	Regional	155	57.4	72 (58; 88)	8.7 (7.5; 10.1)	6.6	69.0	23.2
Netherlands	Clinic	1392	46.8	63 (55; 75)	7.9 (7.2; 9.0)	2.9	83.1	60.6
Canada	Clinic	419	51.1	67 (56; 79)	8.3 (7.2; 9.3)	17.7	83.9	41.3
Ireland	Clinic	222	49.5	71 (62; 80)	8.6 (7.8; 9.5)	24.3	76.9	17.6
France	Clinic	142	47.2	64 (53; 75)	8.0 (7.0; 9.0)	0.0	83.1	33.1
Greece	Clinic	122	53.3	56 (50; 66)	7.3 (6.7; 8.2)	5.7	76.2	21.3

(Continues)

TABLE 1 (Continued)

Country or region	Data source	N	Male (%)[a]	Median HbA_{1c} mmol/mol (IQR)	HbA_{1c} % (IQR)	Missing HbA_{1c} (%)[a]	Diabetes duration ≥5 years (%)[a]	CSII use (%)[a]
≥ 25 years								
England	National	221,545	56.3	66 (57; 78)	8.2 (7.4; 9.3)	10.2	85.7	8.1
Sweden	National	43,510	55.7	58 (51; 67)	7.5 (6.8; 8.3)	1.5	93.4	22.6
Belgium	National	30,398	55.0	58 (52; 67)	7.5 (6.9; 8.3)	2.3	90.5	12.1
Wales	National	27,160	53.8	68 (58; 80)	8.4 (7.5; 9.5)	13.8	84.3	10.2
Scotland	National	25,844	56.7	67 (58; 79)	8.3 (7.5; 9.4)	12.2	93.0	11.5
Norway	National	12,136	55.1	61 (52; 70)	7.7 (7.0; 8.5)	2.4	90.5	30.9
Germany	National	8644	51.9	58 (50; 68)	7.4 (6.7; 8.4)	7.2	–	12.4
Latvia	National	1958	53.6	67 (57; 80)	8.3 (7.4; 9.5)	31.7	94.8	–
Hong Kong	National	1597	49.1	60 (51; 72)	7.6 (6.8; 8.7)	21.1	76.3	–
Italy	Regional	2468	55.5	61 (53; 69)	7.7 (7.0; 8.5)	1.1	90.5	18.5
Finland	Regional	1130	58.5	64 (56; 74)	8.1 (7.3; 8.9)	7.5	–	–
Canada	Clinic	3454	54.5	62 (54; 70)	7.8 (7.0; 8.6)	8.7	90.7	36.2
Ireland	Clinic	1341	53.5	66 (56; 76)	8.2 (7.3; 9.1)	45.4	91.2	11.4
Netherlands	Clinic	720	49.4	56 (50; 65)	7.3 (6.7; 8.1)	5.8	93.2	60.8
France	Clinic	644	51.1	64 (53; 75)	8.0 (7.0; 9.0)	0.0	91.2	59.9
Greece	Clinic	358	45.0	58 (52; 68)	7.5 (6.9; 8.4)	2.0	89.5	19.3

Note: Data included were extracted between 2016 and 2020 (see Figure S1 for details).

[a]Patients with missing information were not included in the denominator.

[b]Data are for individuals aged 18–24 years.

[c]Data are for individuals aged 15–18 years.

[d]Data are for individuals aged 15–21 years.

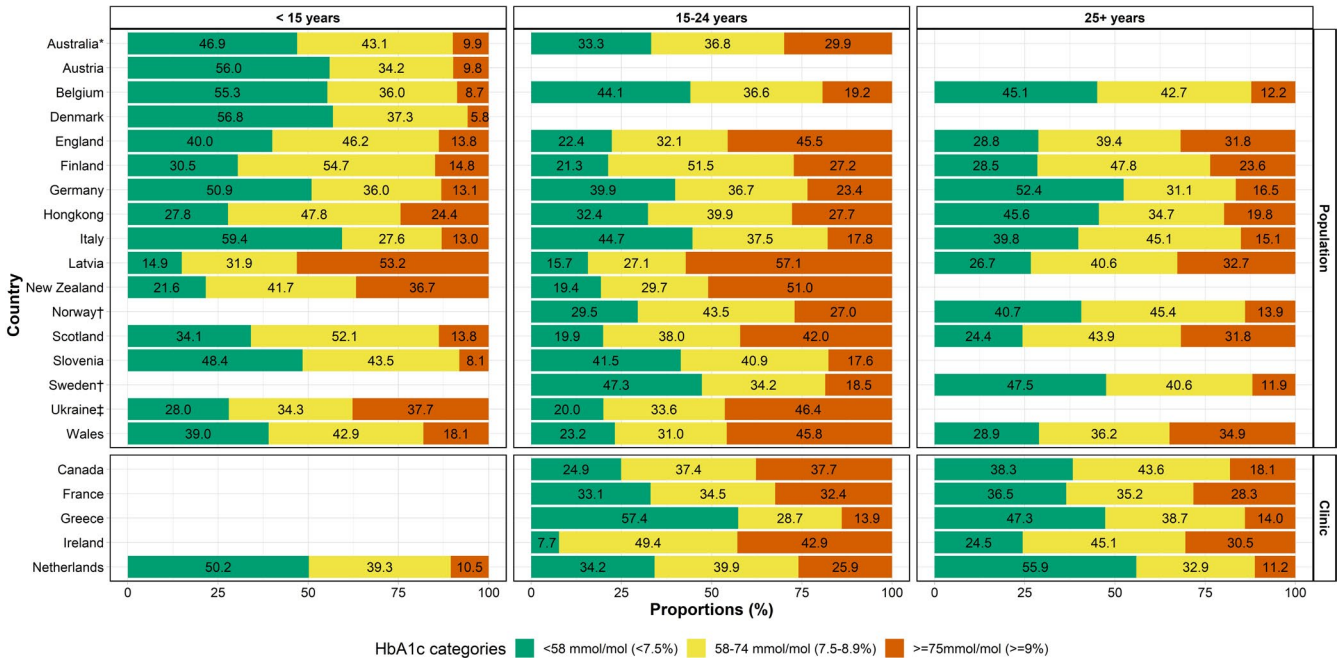

FIGURE 1 Proportions of individuals in each HbA1c category in each of the three age groups by country and type of data source. *Data in age group 15–24 years are for individuals aged 15–21 years. †Data in age group 15–24 years are for individuals aged 18–24 years. ‡Data in age group 15–24 years are for individuals aged 15–18 years

population-based registers (Austria, Australia, Belgium, Denmark, England, Finland, Germany, Hong Kong, Italy, Latvia, New Zealand, Norway, Scotland, Slovenia, Sweden, Ukraine and Wales) and five clinic-based registers (Canada, France, Greece, Ireland, Netherlands). Details of the different data sources including their representativeness and how diagnosis of type 1 diabetes was validated are given in Table S1. The time periods for each data source over the 2016–2020 period are described in Figure S1. Sample sizes ranged from 479 (New Zealand) to 283,414 (England) prior to exclusion of people with missing data and restriction to data from countries where information was available for more than 100 people in each age group (Table S2). Data were not available for all groups for all countries, for example, when data for children and adults are not collected in the same register.

3.2 | Descriptive statistics

In total, data were available for 54,158 children aged <15 years, 83,065 young adults aged 15–24 years, and 382,907 adults aged ≥25 years (see Table 1 for further detail including type of data source as national, regional or clinic where national or regional data were estimated to cover over 80% of the relevant population). Median HbA_{1c} ranged from 55 to 79 mmol/mol (7.2 to 9.4%) across populations and age groups. The proportion of individuals using CSII varied from 2.2% to 74.8% among children aged <15 years, 1.0% to 74.6% among young adults aged 15–24 years, and 8.1% to 60.8% among adults aged ≥25 years. The proportion of individuals who have had diabetes for at least 5 years varied from 32.0% to 75.0%, 62.8% to 83.9%, and 76.3% to 94.8% among the three age groups respectively.

The proportion of individuals with HbA_{1c} ≥ 75 mmol/mol (≥ 9.0%) varied between data sources (Figure 1). Proportions with HbA_{1c} ≥ 75 mmol/mol (≥ 9.0%) were lower in clinic-based than population-based data sources among children aged <15 years (10.5% vs. 16.1%), young adults aged 15–24 years (28.9% vs. 37.5%), and adults aged ≥25 years (19.8% vs. 26.7%). Among all age groups, the proportion with HbA_{1c} ≥ 75 mmol/mol (≥9.0%) was slightly lower and the proportion with HbA_{1c} < 58 mmol/mol (<7.5%) was slightly higher among men than among women (Table S3). In the majority of countries, the proportion of individuals using CSII was lowest among those with HbA_{1c} ≥ 75 mmol/mol (≥9.0%) (Figure 2). For populations with data available for HbA_{1c} < 48 mmol/mol (<6.5%), the proportions of people in each of the five HbA_{1c} categories in the three age groups by countries and data sources are presented in Figure S2.

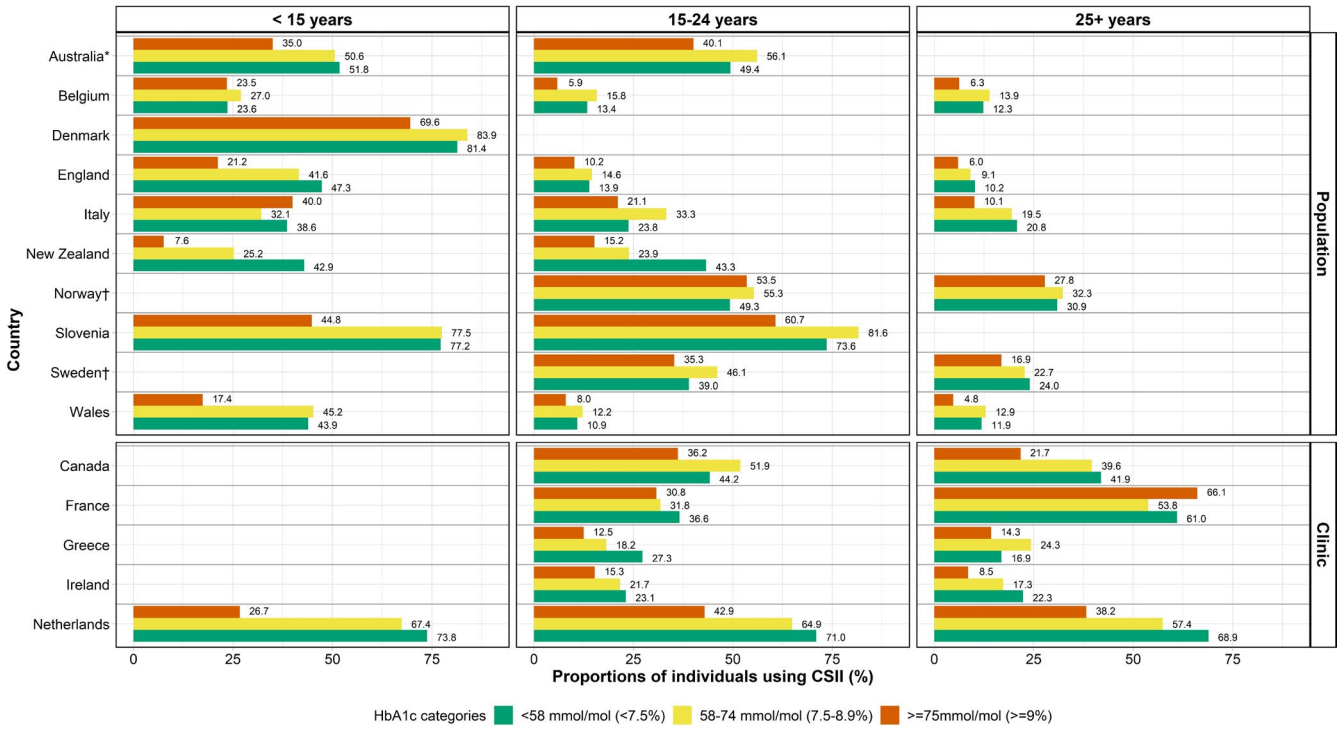

FIGURE 2 Proportions of individuals using CSII by HbA1c category and country and type of data source in each of the three age groups. *Data in age group 15–24 years are for individuals aged 15–21 years. †Data in age group 15–24 years are for individuals aged 18–24 years

TABLE 2 Odds ratios (95% CI) for HbA_{1c}<58 mmol/mol for sex, age, data source, and country

	Overall		Data source			
			Population-based		Clinic-based	
Variable	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***
Sex						
Female	0.91 (0.90; 0.92)	<0.001	0.91 (0.90; 0.92)	<0.001	0.89 (0.81; 0.97)	0.011
Male	ref.	–	ref.	–	ref.	–
Age groups						
< 15 years	1.68 (1.65; 1.71)	<0.001	1.42 (1.39; 1.46)	<0.001	0.93 (0.76; 1.14)	0.469
15 – 24 years	0.81 (0.79; 0.82)	<0.001	0.77 (0.76; 0.78)	<0.001	0.52 (0.46; 0.60)	<0.001
≥ 25 years	ref.	–	ref.	–	ref.	–
Data source						
Clinic	1.24 (1.19; 1.30)	<0.001	–	–	–	–
Population	ref.	–	–	–	–	–
Country (population based)						
Australia	–	–	1.57 (1.38; 1.77)	<0.001	–	–
Austria	–	–	2.21 (1.98; 2.46)	<0.001	–	–
Belgium	–	–	2.09 (2.05; 2.14)	<0.001	–	–
Denmark	–	–	2.29 (2.07; 2.54)	<0.001	–	–
Finland	–	–	0.94 (0.84; 1.06)	0.340	–	–
Germany	–	–	2.08 (2.03; 2.13)	<0.001	–	–
Hong Kong	–	–	1.74 (1.58; 1.91)	<0.001	–	–
Italy	–	–	1.77 (1.64; 1.90)	<0.001	–	–
Latvia	–	–	0.71 (0.64; 0.79)	<0.001	–	–
New Zealand	–	–	0.55 (0.44; 0.68)	<0.001	–	–
Norway	–	–	1.65 (1.59; 1.71)	<0.001	–	–
Scotland	–	–	0.80 (0.78; 0.83)	<0.001	–	–
Slovenia	–	–	1.91 (1.65; 2.21)	<0.001	–	–
Sweden	–	–	2.30 (2.25; 2.34)	<0.001	–	–
Wales	–	–	1.00 (0.98; 1.03)	0.768	–	–
England	–	–	ref.	–	–	–
Country (clinic based)						
France	–	–	–	–	1.01 (0.85; 1.18)	0.946
Greece	–	–	–	–	1.88 (1.55; 2.29)	<0.001
Ireland	–	–	–	–	0.48 (0.41; 0.57)	<0.001
Netherlands	–	–	–	–	1.75 (1.53; 2.01)	<0.001
Canada	–	–	–	–	ref.	–

Note: Data included were extracted between 2016 and 2020 (see Figure S1 for details).

3.3 | Comparison of glycaemic outcome between centres and over time

Differences between populations persisted after adjusting for sex, age and data source (Table 2). Adjusted odds ratios (95% CI) for HbA_{1c} < 58 mmol/mol (<7.5%) were 1.24 (1.19–1.30) for clinic-based data compared to population-based data. In analyses stratified by type of data source, differences between populations persisted after adjusting for sex and age. Among population-based registers, adjusted odds ratios (95% CI) for HbA_{1c} < 58 mmol/mol (<7.5%) were 0.91 (0.90–0.92) for women compared to men, 1.42 (1.39–1.46) and 0.77 (0.76–0.78) for people aged <15 years and 15–24 years compared to those aged ≥25 years, respectively. For data from clinic-based registers, adjusted odds ratios (95% CI) for HbA_{1c} < 58 mmol/

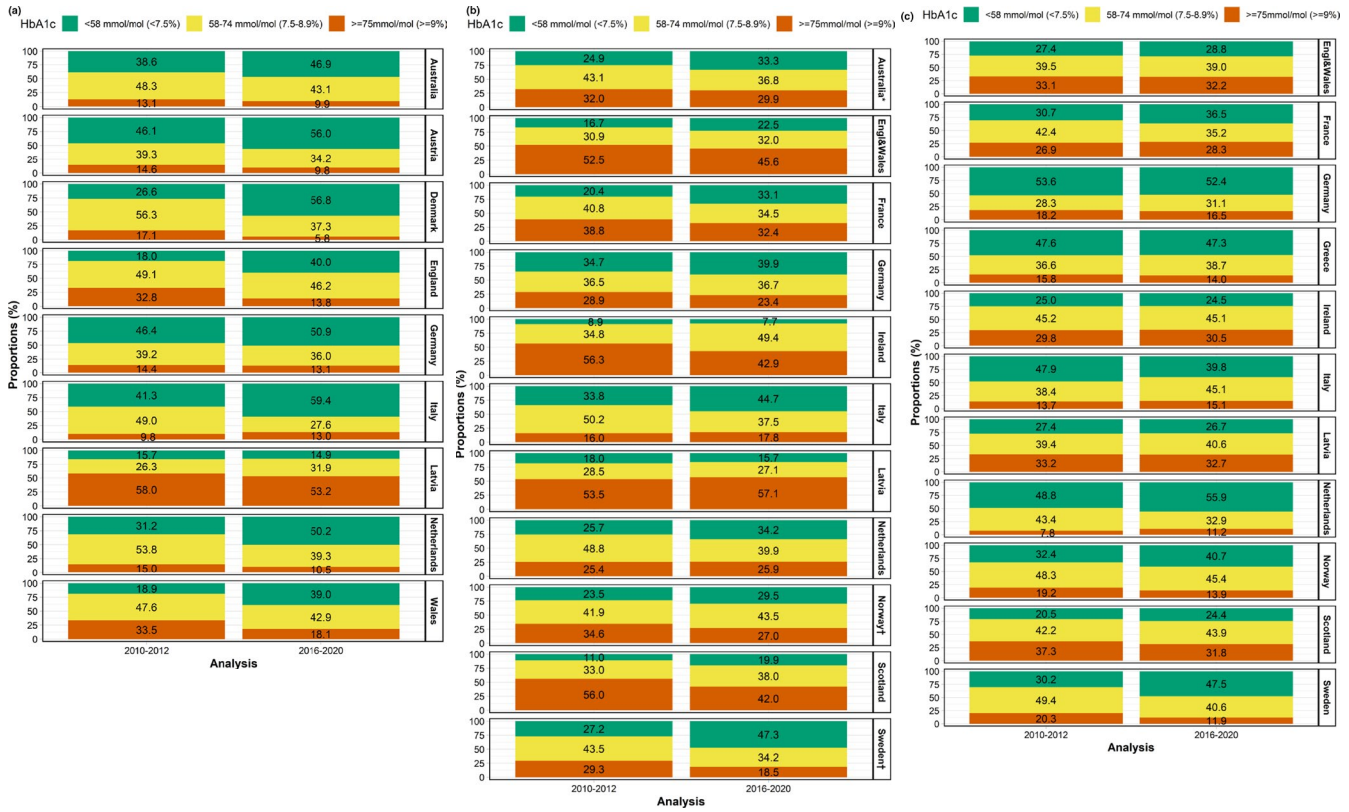

FIGURE 3 Analysis of change between 2010–2012 and 2016–2020 time periods in the proportions of individuals in each HbA1c category in each of the three age groups for countries that had contributed to both the previous and current international comparison: (a) <15 years old, (b) 15–24 years old, (c) ≥25 years old. *Data in age group 15–24 years are for individuals aged 15–21 years. †Data in age group 15–24 years are for individuals aged 18–24 years

mol (<7.5%) were 0.89 (0.81–0.97) for women compared to men, 0.93 (0.76–1.14) and 0.52 (0.46–0.60) for people aged <15 years and 15–24 years compared to those aged ≥25 years respectively.

In the majority of data sources that have contributed to both our previous and current international comparison, the proportion of people with HbA_{1c} < 58 mmol/mol (<7.5%) increased and the proportion of people with HbA_{1c} ≥ 75 mmol/mol (≥9.0%) decreased over time (Figure 3a–c). Tables S4–S6 describe the absolute and relative change in the proportion of people with HbA_{1c} ≥ 75 mmol/mol (≥9.0%) for the population with available data for each of the three age groups.

4 | DISCUSSION

Our data, describing glycaemic control from over half a million people with type 1 diabetes across 22 different countries, clearly demonstrate the challenge of achieving lower HbA_{1c} targets to minimize the risk of developing long-term complications. Glycaemic control continues to vary substantially between age groups, countries and type of data source, with large proportions of people with HbA_{1c} ≥ 75 mmol/mol (≥9.0%), particularly among people aged 15–24 years. A small proportion of people in each population achieve the tighter glycaemic targets recommended in recent guidelines.[5] We have also shown better glycaemic control in children compared to adults with type 1 diabetes in population-based data. As we did not have access to individual level data, we were not able to establish whether the variations in improvements in glycaemic control over time by age group in this analysis were statistically significant.

The use of new technologies such as CSII, CGM and closed loop, sensor augmented CSII devices are associated with lower HbA_{1c}[11–15] but they were not available to all the populations studied in this report. Previous Scottish studies have shown lower HbA_{1c} in people using CSII in a clinic population[16] and time trends between 2004 and 2016 in declining HbA_{1c} across the whole Scottish population of people with type 1 diabetes, with the most marked improvements in children and adolescents.[17]

Data from the National Paediatric Diabetes Audit in England and Wales technologies spotlight audit have demonstrated a 6 mmol/mol lower HbA_{1c} in those using CSII in combination with CGM compared to multiple

daily injections alone independent of ethnicity, duration of diabetes or social deprivation.[18] There are several possible explanations for the difference in glycaemic control, including allocation bias arising from the fact that characteristics of people that receive CSII differ from those that do not receive CSII in many settings. In addition, local resource and support for those initiating and continuing CSII is likely to vary within and across populations. The association between use of technology and proportions achieving glycaemic targets may not be consistent within or across different settings.

It is possible that some of the differences between populations and changes over time could be explained by the extent of introduction of new technologies at the time of the data extraction. However we did not observe any association between proportions of each population using CSII and median HbA1c (using data reported in Table 1). We did not collect data on the use of CSII and CGM for our previous analysis or on CGM for this analysis and have therefore not been able to explore their role in temporal changes. The fact that data included in this comparison were extracted between 2016 and 2020 (although most data were for 2018–2019, see Figure S1) and the use of technologies differs between countries limits direct comparisons. Other important contributing factors to differences between populations that we were unable to consider include socioeconomic deprivation, educational attainment, diet, eating habits, ethnicity, physical activity, diabetes education, social and psychological support and health systems including insurance coverage in some countries.

Despite noting that many people do not achieve recommended glycaemic targets, we have found an improvement in glycaemic control among people with type 1 diabetes in most countries over time, though to a greater extent in some than others, but particularly amongst those aged <15 years. This is encouraging and is likely to be due to a combination of the factors described above.

This analysis has several possible limitations, including selection bias. We have described our data sources in detail. The data from clinics are more likely to be affected by selection bias than those from population-based datasets but missing data may introduce bias in population-based datasets. It seems probable that data are more likely to be missing from people with poor engagement with services who are less likely to have good control, as illustrated by data from north-east Scotland.[19] Although we have described data sources using the name of the country of origin, it is important to recognise that some of these datasets may not be representative of the wider community of people with diabetes in that country if regional differences exist or clinic-based populations are a selected sub-group of the population of interest. We did not collect data on duration of diabetes that would have been needed to subdivide data for the oldest age-group that includes both people with type 1 diabetes since childhood and people who developed type 1 diabetes as adults.

Some variability in HbA_{1c} values might be caused by different laboratory methods in our populations, even if all national standards for good laboratory practice were met. In addition, it was not possible to compare the incidence of hypoglycaemic episodes, use of different types of CSII, glucose sensors or any sensor-augmented systems.

We have demonstrated differences in glycaemic control in different populations and age groups and shown that differences persist between populations over time. Further research is required to better understand whether apparent differences between health systems may relate to such influences as societal factors, structure and delivery of clinical care and resource allocation. Their better understanding could help inform development of cost-effective interventions to improve outcomes. Our data reinforce existing knowledge that adolescence and early adulthood is a particularly challenging time for managing type 1 diabetes and that there is considerable scope for improving glycaemic control in this age group in most populations. The consistent pattern of improvement in those <15 years is the greatest encouragement, and it will be informative to see if it continues as this group becomes older. In general, data that are available for children are more representative than for adults and subsequent analysis of better quality data would be helpful to address the limitations of this work.

It is possible that wider use of newer technologies including sensors and closed loop systems could contribute to further improvements in glycaemic control, particularly among populations where they are not yet available. However, use of technology is only one factor in glycaemic control and maximising the effectiveness of conventional approaches to management of type 1 diabetes, including education, encouraging acceptance of the condition and frequent glucose measurement, remain important. These latter aspects are obviously particularly relevant in low resource settings although all health services need to adapt to changes in the available technology.

ACKNOWLEDGEMENTS

Austria: The authors have submitted this work on behalf of the German/Austria DPV database. We would like to thank all Austrian diabetes centers contributing data to the DPV-registry, especially the multidisciplinary diabetes teams, the persons with diabetes and their families, as well as the team of Prof. Holl in Ulm, Germany for their support. **Belgium:** The authors have submitted this work on behalf of the Belgian Group of Experts IQECAD and IQED We would like to thank the Group of Expert team

members (IQED: Prof. Dr. L. Crenier, Prof. Dr. C. De Block, Prof. Dr. C. Mathieu, Dr. F. Nobels, Dr. P. Oriot, Dr. M. Vandenbroucke, Dr. V. Vanelshocht and Dr. A. Verhaegen; IQECAD: Dr. V. Beauloye, Dr. D. Beckers, Dr. K. Casteels, Dr. M. Den Brinker, Dr. S. Depoorter, Dr. L. Dooms, Dr. D. Klink, Dr. M-C. Lebrethon, Dr. J. Louis, Dr. K. Logghe, Dr. N. Seret, Dr. S. Tenoutasse, Dr. J. Vanbesien, Dr. S. Van Aken and Dr. R. Zeevaert) and staff of Belgian specialised diabetes centres. IQED and IQECAD are funded by the Belgian National Institute for Health and Disability Insurance (NIHDI). **Denmark:** We acknowledge with gratitude the nurses, the physicians and the persons with diabetes contributing to the Danish Childhood Diabetes Register (DanDiabKids). **England and Wales:** The authors have submitted this work on behalf of the the National Paediatric Diabetes Audit and the Royal College of Paediatrics and Child Health and the National Diabetes Audit, The National Paediatric Diabetes Audit (NPDA) and the National Diabetes Audit (NDA) acknowledge the commissioning of the audits by the Healthcare Quality Improvement Partnership (HQIP) and the funding by NHS England and the Welsh Government. We thank the Royal College of Paediatrics and Child Health who manage and deliver the NPDA, Alex Berry (Diabetes UK, London, UK) for patient and professional input, and all members of the NDA Core advisory group. The NDA is prepared in collaboration with NHS Digital and is supported by Diabetes UK and Public Health England. We specifically thank Ms Saira Pons Perez, who extracted and prepared NPDA data and Matt Curley, the analyst at NHS Digital, who extracted, quality assured and supplied NDA data. **Finland:** We thank the Siunsote IT-unit for data retrieval and IMPRO research consortium enabling the access to the data. **France:** The authors have submitted this work on behalf of the CARéDIAB Network. **Germany:** The authors have submitted this work on behalf of the German/Austria DPV database. The German DPV registry is funded by the German Center for Diabetes Research (DZD grant 82DZD14A02), the German Robert-Koch-Institute and the German Diabetes Association. **Ireland:** Members of the Galway University Hospitals (GUH) Centre for Diabetes, Endocrinology and Metabolism include Dr Marcia Bell, Prof Fidelma Dunne, Dr Francis Finucane, Prof Timothy O'Brien, Dr Esther O'Sullivan and Dr Niamh T. McGrath. Data were extracted from the GUH Diabetes Clinical, Information System (DIAMOND). We acknowledge the contribution of Louise Carmody in data extraction and management. **Italy:** The authors have submitted this work on behalf of the Clinical Registry of the Marche region, Italy. **Latvia:** We thank all primary care physicians and endocrinologists in Latvia who regularly report the information about their diabetes patients to the Diabetes Register as well as the Centre for Disease Prevention and Control of Latvia for co-operation in providing the research datasets. **Netherlands:** We acknowledge the support of Pim Dekker in data management. **Norway:** We acknowledge with gratitude the contribution of people with diabetes who have consented to having their data recorded in the diabetes register and the diabetes teams at 45 hospitals for reporting data to the diabetes register. The Norwegian Diabetes Register for Adults is financed by the Regional Health Authority in Western Norway. **Scotland:** The authors have submitted this work on behalf of the Scottish Diabetes Research Network Epidemiology Group. We acknowledge with gratitude the contributions of people with diabetes, the staff and organisations involved in providing data, setting up, maintaining and overseeing collation of data for people with diabetes in Scotland. The Scottish Diabetes Research Network is supported by National Health Service (NHS) Research Scotland, a partnership involving Scottish NHS Boards and the Chief Scientist Office of the Scottish Government. We thank Lesley Gardner for administrative support with collating and submitting the manuscript. **Slovenia:** We acknowledge with gratitude the contributions of people with diabetes, the staff of Department of Paediatric Endocrinology, Diabetes and Metabolic Diseases, UMC – University Children's Hospital involved in providing data, setting up, maintaining and overseeing collation of data for people with diabetes in Slovenia. **Sweden:** The authors have submitted this work on behalf of the National Diabetes Register in Sweden. We acknowledge with gratitude the Swedish National Diabetes Register coordinators, the nurses, the physicians and the persons with diabetes contributing to the registry. **Ukraine:** We would like to thank all Ukrainian regional endocrinologists who regularly report the information about their diabetes patients to the Ukrainian Paediatric National Diabetes Register (NDR).

CONFLICT OF INTEREST

None declared.

REFERENCES

1. Nathan DM, DCCT/EDIC Research Group. The diabetes control and complications trial/epidemiology of diabetes interventions and complications study at 30 years: overview. *Diabetes Care*. 2014;37:9-16.
2. American Diabetes Association. Standards of medical care in diabetes—2013. *Diabetes Care*. 2013;36:S11-S66.
3. IDF/ISPAD. 2011 Global Guideline for Diabetes in Childhood and Adolescence. 2013.
4. Scottish Intercollegiate Guidelines Network. *Management of Diabetes: A National Clinical Guideline*. Scottish Intercollegiate Guidelines Network; 2017. Accessed December 22, 2021. https://www.sign.ac.uk/assets/sign116.pdf

5. American Diabetes Association. 6. Glycemic targets: standards of medical care in diabetes—2020. *Diabetes Care*. 2020; 43:S66-S76.
6. DiMeglio LA, Acerini CL, Codner E, et al. ISPAD clinical practice consensus guidelines 2018: glycemic control targets and glucose monitoring for children, adolescents, and young adults with diabetes. *Pediatric Diabetes*. 2018;19(Suppl 27):105-114.
7. Diabetes Control and Complications Trial (DCCT)/ Epidemiology of Diabetes Interventions and Complications (EDIC) Study Research Group. Intensive diabetes treatment and cardiovascular outcomes in type 1 diabetes: The DCCT/EDIC study 30-year follow-up. *Diabetes Care*. 2016;39: 686-693.
8. McKnight JA, Wild SH, Lamb MJ, et al. Glycaemic control of Type 1 diabetes in clinical practice early in the 21st century: an international comparison. *Diabetic Med*. 2015;32:1036-1050.
9. Saiyed M, Hasnani D, Alonso GT, Richmond E, Besançon S, Cotterill A, Ngwu U, Mazza C, Rottembourg D, Lanzinger S. SWEET study group. Worldwide differences in childhood type 1 diabetes: the SWEET experience. *Pediatr Diabetes*. 2021;22(2): 207-214.
10. DiMeglio LA, Evans-Molina C, Oram RA. Type 1 diabetes. *Lancet*. 2018;391(10138):2449-2462.
11. Bekiari E, Kitsios K, Thabit H, et al. Artificial pancreas treatment for outpatients with type 1 diabetes: systematic review and meta-analysis. *BMJ*. 2018;361: k1310.
12. Cappon G, Vettoretti M, Sparacino G, Facchinetti A. Continuous glucose monitoring sensors for diabetes management: a review of technologies and applications. *Diabetes Metab J*. 2019;43:383-397.
13. Gordon I, Rutherford C, Makarounas-Kirchmann K, Kirchmann M. Meta-analysis of average change in laboratory-measured HbA1c among people with type 1 diabetes mellitus using the 14 day flash glucose monitoring system. *Diabetes Res Clin Pract*. 2020;164: 108158.
14. Martin CT, Criego AB, Carlson AL, Bergenstal RM. Advanced technology in the management of diabetes: which comes first-continuous glucose monitor or insulin pump? *Curr Diab Rep*. 2019;19:50.
15. Pala L, Dicembrini I, Mannucci E. Continuous subcutaneous insulin infusion vs modern multiple injection regimens in type 1 diabetes: an updated meta-analysis of randomized clinical trials. *Acta Diabetol*. 2019;56:973-980.
16. Tyndall V, Stimson RH, Zammitt NN, et al. Marked improvement in HbA(1c) following commencement of flash glucose monitoring in people with type 1 diabetes. *Diabetologia*. 2019;62:1349-1356.
17. Mair C, Wulaningsih W, Jeyam A, et al. Glycaemic control trends in people with type 1 diabetes in Scotland 2004–2016. *Diabetologia*. 2019;62:1375-1384.
18. Royal College of Paediatrics and Child Health. *NPDA spotlight audit report on diabetes-related technologies 2017–18*. Royal College of Paediatrics and Child Health; 2019. Accessed December 22, 2021. https://www.rcpch.ac.uk/sites/default/files/2019-09/npda_spotlight_report_tech_2019_final.pdf
19. Elders V, Keen A, Gold A. Adults with type 1 diabetes: what factors are associated with disengagement from health services? *Practical Diabetes*. 2014;31:117-118a.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Prigge R, McKnight JA, Wild SH, et al. International comparison of glycaemic control in people with type 1 diabetes: an update and extension. *Diabet Med*. 2021;00:e14766. doi:10.1111/dme.14766