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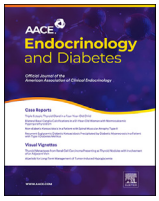

Original Article

Enhancing Diabetes Management in Remote Regions: Insulin Pump Adaption and Safety in the Faroe Islands

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ABSTRACT

Background/Objective: Insulin pump therapy (IPT) is increasingly used in the management of type 1 diabetes, including in remote areas such as the Faroe Islands, where access to diabetes technology is universally reimbursed. However, evidence on its effectiveness in such settings remains limited. This study compared glycated hemoglobin (HbA1c), complications, and renal outcomes between users of IPT and multiple daily injections (MDI).
Case Report: We conducted a nationwide, cross-sectional, registry-based study in the Faroe Islands, linking electronic medical records, prescription data, and laboratory results.
Discussion: Continuous glucose monitoring was used by 92% of participants, and IPT by 50%, primarily hybrid closed-loop systems. Despite higher IPT use among younger individuals, longer diabetes duration was also associated with increased IPT use, suggesting it is often initiated in those with established T1D following challenges with MDI. HbA1c levels did not differ significantly between groups, but severely increased albuminuria was more common in MDI users, while IPT users had better-preserved renal function. Overall, 42% of participants achieved an HbA1c below 53 mmol/mol (7%).
Conclusion: In this setting with broad access to diabetes technology, both IPT and MDI supported effective glycemic control, with possible renal benefits observed among insulin pump therapy users.

Introduction

In recent years, diabetes technology has developed greatly and offers a variety of solutions to help diabetes mellitus be effectively managed. These technologies include smart insulin pens, automated insulin delivery systems (AID), insulin pumps, continuous glucose monitorings (CGMs), mobile apps, and telemedicine services. Insulin pump therapy (IPT) enhances glycemic outcomes and quality of life for many persons with Type 1 diabetes mellitus (T1D), yet its impact varies across populations.[1]

Since IPT development in the late 20th century, IPT has evolved from early devices, which were associated with complications,[1] such as diabetic ketoacidosis (DKA) and injection site infections,[2] to modern systems that integrate with CGMs, known as hybrid

Abbreviations: ACE, angiotensin-converting enzyme inhibitors; ACR, albumin creatinine ratio; AID, automated insulin delivery systems; AT2, angiotensin II receptor antagonists; ATC, Anatomical Therapeutic Chemical classification system; BMI, body mass index; BP, blood pressure; CGM, continuous glucose monitor; CSII, continuous subcutaneous insulin infusion; DKA, diabetic ketoacidosis; eGFR, estimated glomerular filtration rate; EMR, electronic medical records; GAD65, autoantibodies to glutamic acid decarboxylase; GP, general practitioner; HbA1c, glycated hemoglobin; HT, hypertension; ICD-10, International Classification of Diseases and Related Health Problems codes; IPT, insulin pump therapy; isCGM, intermittently scanned continuous glucose monitoring; LDL, low-density lipoprotein; LGS, low-glucose suspend; MDI, multiple daily injections; rtCGM, real-time continuous glucose monitoring; SMBG, self-monitoring of blood glucose; T1D, type 1 diabetes; TIR, time in range; UACR, urine albumin to creatinine ratio.

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closed-loop systems or AID, enabling precise insulin adjustments.[3-5] These developments have established IPT as a fundamental treatment for T1D, providing enhanced glycemic control,[6] reduced DKA incidence and lower variability in glycated hemoglobin (HbA1c) relative to multiple daily injections (MDI).[7,8] Still, some studies have reported a slightly increased risk of hospitalized DKA associated with IPT.[9] Recent data from pediatric populations reveal that from 2013 to 2022, the incidence of DKA events declined from 3.1 to 2.2 per 100 person-years.[10]

Real-time continuous glucose monitoring has demonstrated significant benefits in improving glycemic control and reducing hypoglycemia compared with self-monitoring of blood glucose (SMBG) in individuals with T1D, regardless of the insulin delivery method used.[11] The Integration of CGM with IPT is linked to lower severe hypoglycemia occurrences and better quality-of-life results.[6] Advanced IPT systems, particularly AIDs, are linked to reduced glycemic variability, potentially reducing the risk of microvascular complications such as retinopathy[12] and nephropathy.[12,13]

Between 2013 and 2022, diabetes technology, including IPT and CGM, reduced mean HbA1c from 8.2% (66.5 mmol/mol) to 7.6% (59.4 mmol/mol) and increased the proportion of children meeting HbA1c targets below 53 mmol/mol from 19.0% to 38.8%.[10]

Although much of the initial evidence for these technologies centered on children and younger adults, recent studies have shown that older adults with T1D also benefit from advanced diabetes management technologies. Sensor-augmented pumps and low-glucose suspend functionality are safe and effective in patients aged 60 and above after 1 year of utilisation.[14] Despite the efficacy of advanced diabetes technologies across different age groups, individual characteristics, including baseline HbA1c, age, sex, and CGM use, play a significant role in determining the extent of glycemic improvement.[5,15-17] Personal characteristics affect treatment outcomes, and the accessibility and implementation of diabetes technology differ significantly among locations, influenced by healthcare infrastructure, economic conditions, and governmental frameworks.

Despite the widespread adoption of IPT in countries such as the United States, where 63% of adults with T1D use it in certain settings, this practice remains substantially lower in Europe (5% to 15%) and other regions due to barriers such as cost[18] and a lack of trained physicians.[3,4] In contrast, remote areas such as the Faroe Islands have achieved universal access to diabetes technology, including IPT, through public health insurance coverage. Since 1990, individuals with T1D have been treated at the diabetes clinic at the National Hospital, which has been part of the Steno Diabetes Center Faroe Islands since 2022. Individuals with T1D must apply to the Public Health Insurance system for an insulin pump, accompanied by a medical statement from their physician endorsing its necessity. Upon approval, the request is generally sanctioned and refunded.

Empirical data on the efficacy of IPT in remote environments are limited, especially concerning its influence on glycemic outcomes. This study aims to estimate the utilisation of diabetes technology among individuals with T1D in the Faroe Islands, assess the prevalence of IPT usage, and compare HbA1c outcomes between IPT and MDI users. Furthermore, we explored the association of the use of technology with diabetes-related complications. Studying this special environment will help us to provide insights to optimize IPT use and guide treatment plans for people with T1D, even in remote regions. This study also offers an unprecedented Faroe Islands T1D prevalence estimate.

Highlights

- A nationwide registry study compared clinical characteristics and outcomes in adults with type 1 diabetes (T1D) in the Faroe Islands treated with either insulin pump therapy (IPT) or multiple daily injections (MDI)
- Approximately half of the participants used IPT, which was more frequent among younger adults and individuals with a longer duration of T1D
- Glycemic control, measured by HbA1c, was comparable between IPT and MDI users; 42% of participants achieved HbA1c levels below 53 mmol/mol (7%)
- Indicators of renal function were more favorable among IPT users, with a higher proportion maintaining a normal estimated glomerular filtration rate and lower prevalence of severe albuminuria compared with MDI users
- The majority of participants (92%) utilized continuous glucose monitoring, reflecting broad access to diabetes technology in this setting
- These findings suggest that structured access to advanced diabetes management technologies may contribute to maintaining treatment targets and preserving renal function in remote populations

Clinical Relevance

This study demonstrates that insulin pump therapy can be implemented safely and effectively in geographically remote and resource-constrained settings. In the Faroe Islands, persons with type 1 diabetes have universal access to diabetes technology, with treatment choices guided by specialized staff and fully covered by public health care. Both pump users and those on multiple daily injections achieved favorable glycemic outcomes, suggesting that patients are being appropriately matched to therapy. These findings offer practical insights for clinicians and health care systems aiming to optimize diabetes care delivery in isolated regions and in publicly funded health care models.

Methods

Data Collection

This observational, cross-sectional study utilized register-based, nationwide data encompassing all individuals aged 18 and older diagnosed with T1D residing in the Faroe Islands. Data were obtained from the unified Electronic Medical Record (EMR) system, which includes clinical documentations, medical prescriptions, and laboratory results across all levels of care. Additional HbA1c values, recorded in both outpatient and inpatient settings, were incorporated to verify T1D diagnosis and characterize glycemic status.

The study population included all residents of the Faroe Islands, with data covering the period from 2006 to 2024. The extraction date was 14th August 2024 (total Faroese population $n = 54\,505$[19]; population 18 years and older $n = 41\,472$).

To define T1D prevalence, data were extracted from EMR. Individuals were identified in the EMR using the ICD-10 code for T1D (DE10), medication records, and HbA1c levels. All medical records were reviewed by 2 endocrinologists (J.A. and H.L.J.) to ensure

diagnostic accuracy. Where uncertainty existed regarding the T1D diagnosis, available data on C-peptide and autoantibodies were assessed according to clinical guidelines. Individuals diagnosed with other forms of diabetes mellitus were excluded. A flowchart detailing participant inclusion and exclusion is provided (Fig. 1). Prevalence was estimated, including all identified adults with T1D, regardless of disease duration. However, individuals with a duration of less than 1 year were excluded from analyses of clinical outcomes to reduce bias from early treatment phases. HbA1c levels are often unstable during the first year following diagnosis, and treatment regimens, particularly the use of IPT, may not yet be fully established.

An algorithm was developed to identify insulin pump therapy (IPT) users. Individuals were classified as IPT users if they had at least one recorded ICD-10 procedure code related to IPT in the EMR (eg, Attachment of Insulin Pump [ZZ4075], Insulin Pump Therapy [BBHF02], or Replacement of Insulin Pump [ZZ4073]). Manual validation showed a 95% concordance with the algorithm, with discrepancies resolved through review. Due to limitations in the available registry data, it was not possible to distinguish between specific types of insulin pump therapy, such as the type of hybrid closed-loop systems.

Demographic characteristics (age, sex, weight, and height) and baseline clinical parameters were extracted from EMR, including body mass index (BMI), blood pressure (BP), renal function, cholesterol levels, comorbidities, age at T1D onset, and T1D duration. Biochemical indicators included HbA1c, total cholesterol, triglycerides, low-density lipoprotein (LDL), estimated glomerular filtration rate (eGFR), urine albumin-to-creatinine ratio (UACR), autoantibodies and C-peptide levels. The most recent HbA1c measurement from the past year and other biochemical indicators from the preceding 2 years were used.

Medication data were classified according to the Anatomical Therapeutic Chemical system to identify treatments for glycaemia, blood pressure, and lipids. Additionally, health care access, including the frequency of visits to healthcare providers and Healthcare utilization, including the frequency of health care visits and access to diabetes education, were also obtained from the EMR. Hospital admissions were assessed over the past 10 years, with a binary indicator variable created to identify individuals with more than 3 admissions ('Yes' if > 3 admissions, 'No' otherwise). Medical history data included both acute and chronic diabetes-related complications and other comorbid conditions.

Ethical Considerations

This registry study was approved by the local Faroese Data Protection 153, National Hospital, Faroe Islands, and performed according to the Data Protection.

According to Faroese law, a review by an ethics board or patient consent is not required for purely register-based studies.

Statistics

For continuous variables, the mean and standard deviation (SD) were reported for those with a normal distribution. For categorical variables, data were presented as frequencies and percentages. Stratified analyses were conducted to assess factors associated with achieving target HbA1c levels and using IPT. Chi-square or Fisher's exact tests were applied as appropriate for categorical variables, while t-tests or ANOVA were used for continuous variables. Welch's t-test or ANOVA was applied if Levene's test indicated unequal variances.

The prevalence of T1D was calculated by dividing the number of individuals identified with T1D in the Faroe Islands by the total number of Faroese residents as of August 2024. Prevalence was reported for the entire population and adults (≥18 years). The result was expressed as a percentage.

HbA1c levels were log-transformed to approximate normal distribution. Age was categorized into 3 groups: "18-39," "40-64," and "65+."

Renal function was assessed using eGFR, categorized as ≥90, 60-89, and <60 mL/min/1.73 m^2. Due to the small numbers of participants in the lower eGFR ranges, values of 45-59, 30-44, 15-29, and <15 mL/min/1.73 m^2 were combined into the <60 category to ensure sufficient numbers for analysis.

UACR was categorized as "Normal" (<30 mg/g) or "Elevated" (≥30 mg/g). Due to fewer than 5 individuals having values above 300 mg/g, these were grouped into the elevated category.

Lipid profiles were categorized based on LDL cholesterol levels, with values < 2.6 mmol/L considered "Normal" and ≥2.6 mmol/L classified as "Elevated".

BMI was grouped into '<25' (healthy weight), '25.0-29.9' (overweight), "30.0-34.9" (obesity), and '≥35' (severe obesity). Missing values were categorised as "Unknown."

BP was categorized according to the 2018 European Society of Cardiology (ESC) and European Society of Hypertension (ESH) Guidelines.[20] The categories include "Optimal" (<120/80 mmHg), "Normal" (120-129/80-84 mmHg), "High normal" (130-139/85-89 mmHg), and 3 grades of hypertension: "Grade 1 HT" (140-159/

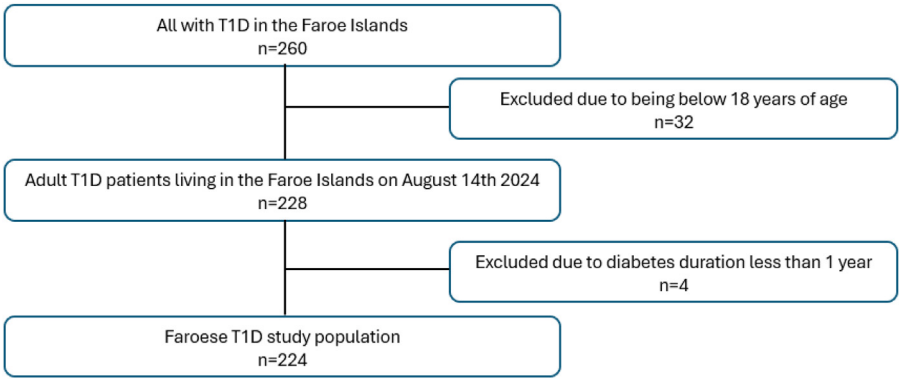

Fig. 1. Flowchart of study population selection. The flowchart illustrates the selection process for the Faroese T1D study population. The final study population consisted of 224 adult individuals with T1D living in the Faroe Islands as of August 14, 2024. *T1D* = type 1 diabetes.

90-99 mmHg), "Grade 2 HT" (160-179/100-109 mmHg), and "Grade 3 HT" (≥180/≥110 mmHg). This classification was applied to reflect clinically relevant cardiovascular risk thresholds and enable comparison with other studies using established guideline criteria.

Diabetes duration was categorized into quartiles based on the distribution of diabetes duration within the study population. The quartiles were defined as 0-9 years, 10-14 years, 15-16 years, and 17 years. The EMR, which was created in 2006, thus, durations exceeding 18 years could not be accurately determined. Therefore, individuals with T1D durations over or equal to 18 years were grouped into a separate category (≥18 years).

Hospital admission frequency was assessed using a binary variable indicating whether an individual had more than 3 hospital admissions within the past 10 years.

Complications of T1D were classified as "Complicated" (DE101-DE108) or "Noncomplicated" (DE109) based on the presence of either acute or chronic diabetes-related conditions, utilizing ICD-10 codes.

Modelling Approach

The assessment of the effect of IPT on HbA1c was conducted using a log-linear model with log HbA1c as the outcome variable. A full additive model was fitted, and the average percentage change of HbA1c associated with IPT use was reported. Due to the high colinearity between CGM use and IPT, CGM was kept out of the main model but was included in the sensitivity analyses for comparison. An interaction term of IPT and sex was added to the model, and the effect of IPT was reported accordingly.

A logistic regression model was fitted to describe the probability of IPT use.

Missing data were addressed using multiple imputations with the "mice" package.[21] Results were reported for both complete case analysis and the imputed dataset.

Data were analyzed using R-Studio Software (version 2024.04.2+764, R Foundation for Statistical Computing). *P* values < 0.05 were considered statistically significant.

Results

Overall Findings

A total of 260 individuals were identified in the Faroe Islands with a T1D diagnosis of which 32 were under the age of 18 years, enabling estimation of T1D prevalence in the entire population and among adults. The prevalence of T1D among the entire Faroese population was estimated at 48 per 10 000 (0.48%) and among adults in the Faroe Islands to 55 per 10 000 (0.55%), with a male-to-female ratio of 1.9:1.

To analyze clinical outcomes, 4 individuals with a diabetes duration of less than 1 year were excluded, as short disease duration may affect treatment stability and HbA1c levels. Consequently, the final study population comprised 224 individuals. The characteristics of the study population are presented in Figure 1 and Table 1.

Among adults with T1D, 42% achieved the treatment target of HbA1c < 7% (53 mmol/mol). Fifty-three percent used IPT, and 92% used CGM. One-third had normal or optimal BP, 82% had normal ACR, and only 5% had chronic kidney disease measured by eGFR. The distribution of HbA1c levels across various demographic, clinical, and biochemical variables is summarized in Table 2.

There were 78 individuals with HbA1c > 7.4% (58 mmol/mol), of whom 37 (47%) used IPT, while 41 (53%) used MDI. Age, sex, and T1D duration did not significantly differ between those achieving the treatment target and those who did not ($P > 0.05$). Notably, HbA1c was slightly lower among females compared with males.

Table 1
Descriptive Statistics of T1D Adult Population in Faroe Islands ($n = 224$)

Variable	Category	Value (geometric) mean/n	(Geometric) SD/%
HbA1c (geometric mean, geometric sd)		54.99	1.21
Target HbA1c < 53 mmol/mol (*n*, %)	No	131	58%
	Yes	93	42%
Age (mean, sd)	Age	49.14	15.73
Age group (*n*, %)	18-39	66	29%
	40-64	114	51%
	≥65	44	20%
Diabetes duration (*n*, %)	0-9 y	58	26%
	10-14 y	54	24%
	15-16 y	79	35%
	17 y	24	11%
	≥18 y	9	4%
Sex (*n*, %)	Female	78	35%
	Male	146	65%
Disease code (*n*, %)	Non-complication	143	64%
	Complication	81	36%
Hospital admissions > 3 (*n*, %)	No	116	52%
	Yes	108	48%
Blood pressure (*n*, %)	Optimal	48	21%
	Normal	36	16%
	High normal	46	21%
	Grade 1 HT	57	25%
	Grade 2 HT	20	9%
	Grade 3 HT	8	4%
	Unknown	9	4%
BMI (*n*, %)	<25	63	28%
	25.0-29.9	96	43%
	30.0-34.9	43	19%
	≥35	17	8%
	Unknown	5	2%
Insulinpump (*n*, %)	No	106	47%
	Yes	118	53%
CGM (*n*, %)	CGM (rtCGM/isCGM)	206	92%
	No sensor	18	8%
LDL (*n*, %)	<2.6	138	62%
	≥2.6	84	38%
	Unknown	2	1%
ACR (*n*, %)	<30	183	82%
	≥30	35	16%
	Unknown	6	3%
eGFR (*n*, %)	<60	12	5%
	60-89	54	24%
	≥90	157	70%
	Unknown	1	0%

Abbreviations: ACR = albumin creatinine ratio; BMI = body mass index; CGM = continuous glucose monitoring; eGFR = estimated glomerular filtration rate; LDL = low-density lipoprotein.
Descriptive statistics of T1D adult population in Faroe Islands ($n = 224$). The type of value for each variable is indicated in column 1. In column 3 mean, or geometric mean are shown for numeric variables, and number of records are shown for categorical variables. In column 4, the standard deviation or geometric standard deviations are shown for numeric variables, and percentages are shown for categorical variables.

Key Clinical Findings

Among IPT users, 89.8% had a normal ACR (0-30 mg/g) vs 72.6% of MDI users ($P = 0.001$). Preserved renal function (eGFR ≥60 mL/

Table 2
Clinical Characteristics of the Faroese Adult T1D Population Stratified by HbA1c, with a Target of <7% (53 mmol/mol) ($n = 224$)

Variable	Category	HbA1c < 53 mmol/mol (n, %)	HbA1c ≥ 53 mmol/mol (n, %)	P	HbA1c (geometric mean, geometric sd)	P
Total		93	131		54.99 (1.21)	
Age groups	18-39	28 (30.1%)	38 (29%)	0.53[a]	56.11 (1.23)	0.35[b]
	40-64	50 (53.8%)	64 (48.9%)		53.98 (1.2)	
	≥65	15 (16.1%)	29 (22.1%)		55.98 (1.22)	
Age (mean, sd)		48.6 (14.5)	49.5 (16.6)	0.65[c]	-	-
Diabetes duration	0-9 y	26 (28%)	32 (24.4%)	0.95[d]	54.72 (1.23)	0.47[b]
	10-14 y	20 (21.5%)	34 (26%)		55.06 (1.2)	
	15-16 y	33 (35.5%)	46 (35.1%)		53.95 (1.19)	
	17 y	10 (10.8%)	14 (10.7%)		57.22 (1.27)	
	≥18 y	4 (4.3%)	5 (3.8%)		59.91 (1.26)	
Sex	Female	34 (36.6%)	44 (33.6%)	0.65[a]	55.11 (1.22)	0.9[b]
	Male	59 (63.4%)	87 (66.4%)		54.93 (1.21)	
Disease code	Noncomplication	58 (62.4%)	85 (64.9%)	0.7[a]	54.61 (1.23)	0.73[b]
	Complication	35 (37.6%)	46 (35.1%)		54.66 (1.19)	
Hospital admissions >3	No	53 (57%)	63 (48.1%)	0.19[a]	53.72 (1.21)	0.06[b]
	Yes	40 (43%)	68 (51.9%)		56.38 (1.21)	
Blood pressure	Optimal	21 (22.6%)	27 (20.6%)	0.64[d]	55.71 (1.24)	0.89[b]
	Normal	18 (19.4%)	18 (13.7%)		53.82 (1.2)	
	High normal	19 (20.4%)	27 (20.6%)		54.64 (1.21)	
	Grade 1 HT	18 (19.4%)	39 (29.8%)		55.96 (1.22)	
	Grade 2 HT	10 (10.8%)	10 (7.6%)		55.22 (1.23)	
	Grade 3 HT	3 (3.2%)	5 (3.8%)		51.04 (1.24)	
	Unknown	4 (4.3%)	5 (3.8%)		54.74 (1.11)	
BMI	<25	21 (22.6%)	42 (32.1%)	0.43[d]	56.72 (1.24)	0.6[b]
	25.0-29.9	45 (48.4%)	51 (38.9%)		54.11 (1.2)	
	30.0-34.9	19 (20.4%)	24 (18.3%)		55.13 (1.21)	
	≥35	7 (7.5%)	10 (7.6%)		54.23 (1.2)	
	Unknown	1 (1.1%)	4 (3.1%)		52.05 (1.25)	
Insulin pump	No	46 (49.5%)	60 (45.8%)	0.59[a]	55.09 (1.25)	0.9[e]
	Yes	47 (50.5%)	71 (54.2%)		54.91 (1.18)	
CGM	CGM (rtCGM/isCGM)	87 (93.5%)	119 (90.8%)	0.46[a]	54.98 (1.2)	0.97[e]
	No sensor	6 (6.5%)	12 (9.2%)		55.14 (1.36)	
LDL	<2.6	64 (68.8%)	74 (56.5%)	0.1[d]	53.51 (1.21)	**0.03**[b]
	≥2.6	28 (30.1%)	56 (42.7%)		57.41 (1.21)	
	Unknown	1 (1.1%)	1 (0.8%)		58.79 (1.33)	
ACR	<30	78 (83.9%)	105 (80.2%)	0.79[d]	54.23 (1.19)	0.18[f]
	≥30	13 (14%)	22 (16.8%)		57.64 (1.3)	
	Unknown	2 (2.2%)	4 (3.1%)		64.1 (1.29)	
eGFR	<60	8 (8.6%)	4 (3.1%)	0.24[d]	50.72 (1.21)	0.24[b]
	60-89	22 (23.7%)	32 (24.4%)		54.73 (1.2)	
	≥90	63 (67.7%)	94 (71.8%)		55.33 (1.22)	
	Unknown	0	1 (0.8%)		-	

Abbreviations: ACR = albumin creatinine ratio; BMI = body mass index; CGM = continuous glucose monitoring; eGFR = estimated glomerular filtration rate; LDL = low-density lipoprotein.
HbA1c levels described for the Faroese T1D adult population stratified. In column 3, the subgroup that have HbA1c levels below 7% (53 mmol/mol) is used, and the numbers are number of records and percentages for categorical variables, and mean and standard deviation for numerical variables. In column 4 the same is shown but for the subgroup having HbA1c levels above or equal to 53 mmol/mol. Column 5 shows P values of test statistics calculated to test for differences of variables when stratified on HbA1c levels below, and equal to or above 53 mmol/mol. Column 6 shows geometric means and geometric standard deviations of HbA1c when stratified on categorical variables. Column 7 shows the P values calculated to test for differences of the logarithm of HbA1c values when stratified on a variable. Statistically significant results ($P < 0.05$) are shown in bold.
[a] Chi-square test.
[b] ANOVA.
[c] T-test.
[d] Fisher's exact test.
[e] Welch's T-test.
[f] Welch's ANOVA.

min/1.73 m^2) was more common among IPT users ($P = 0.04$), whereas reduced renal function (eGFR <60 mL/min/1.73 m^2) was more frequently observed in MDI users (8.5% vs 2.5%).

HbA1c distribution showed limited variation across most clinical variables. However, lower LDL levels (<2.6 mmol/L) were associated with lower HbA1c levels ($P = 0.03$).

No significant associations were found between groups for BP, BMI, and complication status, nor CGM usage. These results indicate that these factors were not substantially associated with glycemic control in our study population.

Figure 2 displays the distribution of HbA1c levels for IPT and MDI users, stratified by sex. HbA1c levels peak around 58-64 mmol/mol in males and females. IPT shows a more centralized distribution, while MDI users exhibit greater variability, particularly in lower and higher HbA1c ranges.

As shown in Table 3, significant differences ($P < 0.05$) between IPT and MDI users were identified for age, diabetes duration, kidney function, albumin-to-creatinine ratio, and CGM use, while BMI differed between groups with borderline significance ($P = 0.07$).

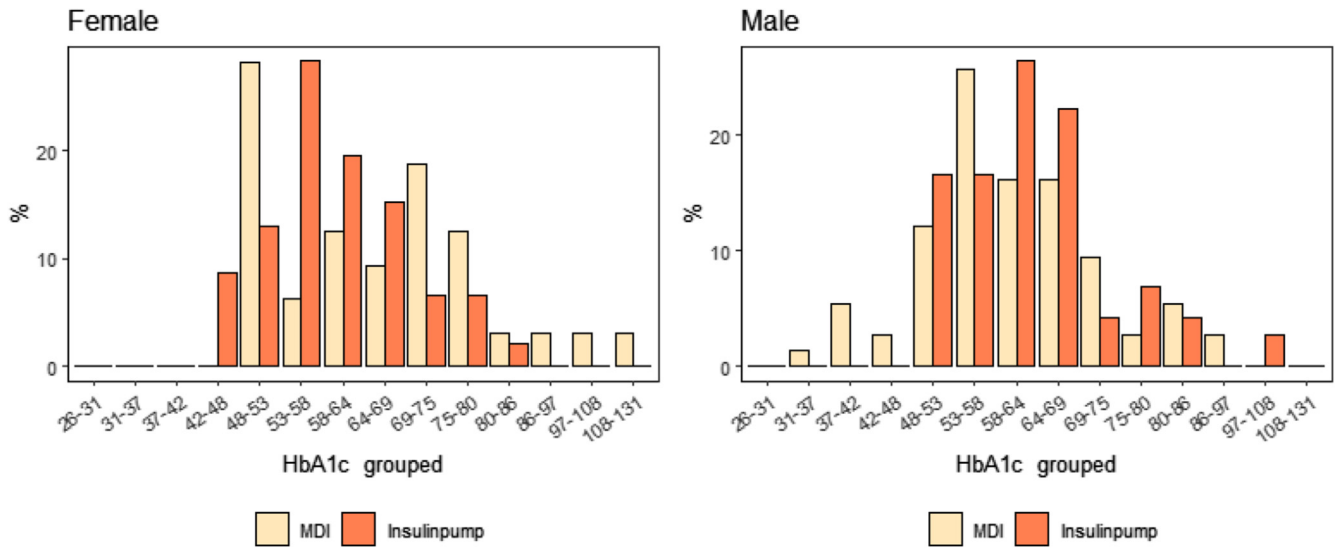

Fig. 2. Distribution of HbA1c levels by insulin therapy and sex in the Faroese Adult T1D population. The histograms illustrate the distribution of glycated hemoglobin (HbA1c) levels in female (left) and male (right) participants, stratified by insulin therapy type. The x-axis represents grouped HbA1c values (mmol/mol), while the y-axis shows the percentage of individuals in each HbA1c category. Individuals using multiple daily injections (MDI) are shown in light yellow, whereas those using insulin pump therapy are represented in orange. The distributions suggest differences in glycemic control between the 2 treatment groups within each sex.

Predictors of IPT use were analysed using logistic regression, with the findings visualised in Figure 3.

Impact of IPT on HbA1c

The initial full additive model ($R^2 = 0.13$, $P = 0.12$) estimated that IPT corresponded with a non-significant change in HbA1c levels, corresponding to a 0.32% decrease in HbA1c levels (95% CI: −6% to +5.7%; $P = 0.92$), suggesting no overall effect of IPT on glycemic control in this cohort.

To further explore potential differences by sex, an interaction term between sex and IPT was added to the model ($R^2 = 0.16$, $P = 0.03$), resulting in improved model fit. In this model, IPT was correlated with a 9.6% reduction in HbA1c levels among females (95% CI: −17.7% to −0.6%, $P = 0.04$), whereas among males, IPT was associated with a 4.9% increase in HbA1c levels (95% CI: −2.2% to +12.5%, $P = 0.18$), although this was not statistically significant.

Analyses based on imputed data yielded comparable results (data not shown).

Discussion

T1D Prevalence in the Faroe Islands

In the Faroe Islands, the estimated prevalence of T1D among adults is 55 per 10 000 (or 550 per 100 000), similar to that of other Nordic populations like Finland, which sees around 600 per 100 000.[22] Worldwide, the prevalence of T1D varies considerably, ranging from approximately 10 per 100 000 in countries such as Japan and China to over 500 per 100 000 in specific European populations, showing significant differences in T1D prevalence worldwide.[23] These findings suggest that the Faroe Islands, like other Nordic countries,[22-26] have an elevated prevalence of T1D, potentially due to robust healthcare systems that support accurate diagnosis and long-term management.

The male-to-female ratio was 1.9:1, consistent with findings from other Nordic countries, where type 1 diabetes is also more common in males. For instance, in Denmark, approximately 56% of individuals with type 1 diabetes are male, while 44% are female.[27] Studies from other Nordic communities also show a higher frequency in boys than in girls, especially in relation to early onset.[28] These results suggest that the observed sex difference may be influenced by shared genetic and environmental factors in the Nordic region.

The finding that 43% of participants were overweight may reflect features of insulin resistance in some individuals, consistent with the concept of "double diabetes,"[29] This pattern likely mirrors population-level trends, as more than half of Faroese adults are overweight or obese according to The Health Authority,[30] placing the Faroe Islands among countries with the highest BMI globally. While markers of insulin resistance were not available, this underscores the need to consider metabolic context in T1D management.

Glycemic Control, CGM, and IPT

In our study, 42% of individuals with type 1 diabetes had an HbA1c level below 7% (53 mmol/mol), higher than the 32% reported in Denmark,[27] and also slightly exceeds global estimates, where only 27% to 40% meet this target.[4,31] The US *"T1D Exchange study"* also indicates that merely 21% of teenagers and 29% of adults attained the recommended HbA1c levels.[32] While the EMR includes both inpatient and outpatient HbA1c results, testing is not routinely conducted during hospital admissions unless clinically indicated. Therefore, the HbA1c values in this study predominantly reflect routine outpatient follow-up care. These findings suggest that Faroese individuals may achieve better glycemic outcomes, potentially due to healthcare access, treatment strategies, or population characteristics. Achieving glycemic goals is a worldwide challenge.[31]

However, the clinical relevance of a universal HbA1c <7% threshold may vary by age; older adults are often managed with more individualized targets, and thus, achieving this threshold may be less clinically meaningful in that group.

In this population, HbA1c levels did not significantly differ between IPT and MDI users, consistent with previous findings that IPT may reduce glycemic variability and hypoglycemia without necessarily improving mean HbA1c.[4,33] This highlights

Table 3
Comparison of Clinical Characteristics in Faroese Adult T1D Patients by Insulin Pump Therapy (IPT) Status ($n = 224$)

Variable	Category	MDI	Insulin pump	*P*
HbA1c (geometric mean, sd)		55.09 (1.25)	54.91 (1.18)	0.9[a]
HbA1c target (*n*, %)	No	60 (56.6%)	71 (60.2%)	0.59[b]
	Yes	46 (43.4%)	47 (39.8%)	
Age (mean, sd)		54.3 (14.65)	44.5 (15.3)	<**0.001**[c]
Age group (*n*, %)	18-39	19 (17.9%)	47 (39.8%)	<**0.001**[b]
	40-64	54 (50.9%)	60 (50.8%)	
	≥65	33 (31.1%)	11 (9.3%)	
Diabetes duration (*n*, %)	0-9 y	36 (34%)	22 (18.6%)	**0.01**[d]
	10-14 y	17 (16%)	37 (31.4%)	
	15-16 y	34 (32.1%)	45 (38.1%)	
	17 y	13 (12.3%)	11 (9.3%)	
	≥18 y	6 (5.7%)	3 (2.5%)	
Sex (*n*, %)	Female	32 (30.2%)	46 (39%)	0.17[b]
	Male	74 (69.8%)	72 (61%)	
Disease code (*n*, %)	Noncomplication	61 (57.5%)	82 (69.5%)	0.06[b]
	Complication	45 (42.5%)	36 (30.5%)	
Hospital admissions >3 (*n*, %)	No	55 (51.9%)	61 (51.7%)	0.98[b]
	Yes	51 (48.1%)	57 (48.3%)	
Blood pressure (*n*, %)	Optimal	22 (20.8%)	26 (22%)	0.21[d]
	Normal	15 (14.2%)	21 (17.8%)	
	High normal	19 (17.9%)	27 (22.9%)	
	Grade 1 HT	35 (33%)	22 (18.6%)	
	Grade 2 HT	6 (5.7%)	14 (11.9%)	
	Grade 3 HT	4 (3.8%)	4 (3.4%)	
	Unknown	5 (4.7%)	4 (3.4%)	
BMI (*n*, %)	<25	37 (34.9%)	26 (22%)	0.07[d]
	25.0-29.9	38 (35.8%)	58 (49.2%)	
	30.0-34.9	18 (17%)	25 (21.2%)	
	≥35	9 (8.5%)	8 (6.8%)	
	Unknown	4 (3.8%)	1 (0.8%)	
CGM (*n*, %)	CGM (rtCGM/isCGM)	95 (89.6%)	111 (94.1%)	0.22[b]
	No sensor	11 (10.4%)	7 (5.9%)	
LDL (*n*, %)	<2.6	70 (66%)	68 (57.6%)	0.23[b]
	≥2.6	36 (34%)	48 (40.7%)	
	Unknown	0	2 (1.7%)	
ACR (*n*, %)	<30	77 (72.6%)	106 (89.8%)	**0.001**[d]
	≥30	26 (24.5%)	9 (7.6%)	
	Unknown	3 (2.8%)	3 (2.5%)	
eGFR (*n*, %)	<60	9 (8.5%)	3 (2.5%)	**0.04**[d]
	60-89	30 (28.3%)	24 (20.3%)	
	≥90	67 (63.2%)	90 (76.3%)	
	Unknown	0	1 (0.8%)	

Abbreviations: ACR = albumin creatinine ratio; BMI = body mass index; CGM = continuous glucose monitoring; eGFR = estimated glomerular filtration rate; LDL = low-density lipoprotein.
IPT (Insulin pump therapy) groups described for the Faroese T1D adult population stratified. Statistics for the 'no pump' are shown in column 3, where geometric means or means are shown for numerical variables and the number of records and percentages for categorical variables. Column 4 shows the same statistics but for the "pump" group. Column 5 shows *P* values of test statistics calculated to test for differences of variable distributions when stratified on IPT. Statistically significant results ($P < 0.05$) are shown in bold.
[a] T-test.
[b] Chi-square test.
[c] Welch's T-test.
[d] Fisher's exact test.

the limitations of HbA1c as a sole metric, as it does not reflect glycemic variability or time in range (TIR), which are increasingly recognized as important markers of glycemic control.[33]

The decision to exclude individuals with <1 year of T1D duration was to avoid misclassification of HbA1c values taken at the time of pump initiation, which may not reflect outcomes of established IPT use. In the context of a small-scale society such as the Faroe Islands, the absolute number of newly diagnosed individuals within a given year is low, which further limits the feasibility of subgroup analysis in this population.

Differences in HbA1c levels between sexes were not significant ($P = 0.7$), yet a larger percentage of women achieved the target HbA1c level. The observed sex differences in target attainment may reflect engagement with diabetes technology, behavioral, or physiological factors, such as differences in adherence or insulin sensitivity; however, these cannot be assessed within the scope of this observational study. Although the results are inconclusive, this corresponds with findings that indicate women might have better glycemic outcomes, possibly because of increased adherence to treatment recommendations,[34] including dietary choices[35] and engagement with healthcare services.[36] Notably, the study cohort was predominantly male (65%), which may have influenced the overall proportion achieving glycemic targets. This imbalance was accounted for in the multivariable regression model, which included sex as a covariate, and sex-stratified results were also examined to minimize bias in estimating treatment effects.

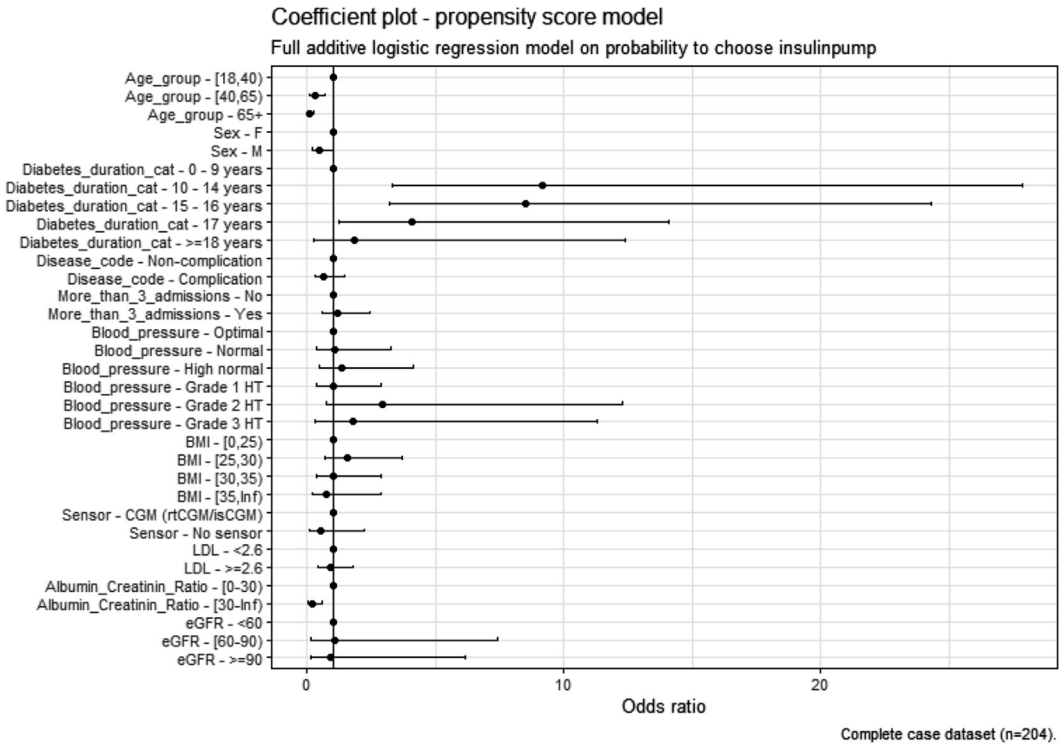

Fig. 3. Logistic regression coefficient plot for insulin pump use. This plot shows odds ratios from a logistic regression model predicting insulin pump use in the Faroese adult T1D population ($n = 204$). The x-axis represents odds ratios, and the y-axis lists predictor variables, including age, sex, diabetes duration, complications, admissions, blood pressure, BMI, CGM use, LDL, albumin-creatinine ratio, and eGFR. Points indicate estimates, with horizontal lines showing 95% confidence intervals. *BMI* = body mass index; *CGM* = continuous glucose monitoring; *eGFR* = estimated glomerular filtration rate; *LDL* = low-density lipoprotein; *T1D* = type 1 diabetes.

The use of CGM was high in this study population (92%), compared to 58% among adults with T1D in Denmark.[27] The increased use of CGM within our study could indicate variations in healthcare accessibility, reimbursement strategies, or patient preferences in the Faroe Islands. However, the small number of individuals not utilizing CGM limited our ability to perform robust subgroup comparisons. In particular, the group of MDI users without CGM was very small and clinically distinct, often including individuals with very low insulin requirements or skin intolerance to sensors, which restricted meaningful comparison with other treatment groups. No significant association was observed between CGM use and HbA1c ($P = 0.5$), suggesting that elements beyond the availability of CGM might have a greater impact on glycemic control.

Given the high overlap between CGM and IPT use, we considered the potential for co-linearity. Sensitivity analyses were conducted by fitting the outcome model with and without CGM as a covariate, and results remained consistent. This supports the interpretation that the observed associations were primarily attributable to IPT, rather than confounding by concurrent CGM use, although residual confounding cannot be entirely excluded.

IPT and Patient Characteristics

IPT use was more common among younger adults in this cohort, while older individuals more frequently used MDI. This age-related trend could indicate that younger individuals are more likely to adopt technology, expect a longer disease duration, and are more acquainted with advancements in diabetes care. Despite the higher uptake of IPT among younger individuals, a longer diabetes duration was also linked to increased IPT use, potentially indicating cumulative treatment experience and the necessity for more advanced management strategies. This suggests that IPT is more frequently initiated in individuals with established T1D, possibly after they have encountered difficulties with MDI. However, it is important to note that the classification of "IPT users" in this study represents a heterogeneous group, potentially including users of automated insulin delivery systems and DIY-modified pumps. The inability to differentiate between specific pump types may have influenced the observed associations.

Despite these demographic differences, IPT use was not significantly associated with achieving the HbA1c target ($P = 0.6$). This contrasts with findings from larger studies and meta-analyses demonstrating modest HbA1c reductions (approximately 0.3% to 0.6%) with IPT use.[13] The efficacy in real-world settings may be affected by aspects like accessibility, adherence, and patient engagement education.[37] Moreover, AID has been connected to a small drop in HbA1c (around 0.39%) relative to MDI.[13] Although technology has advanced, population-level HbA1c still shows minor changes; international averages remain around 8.4% (68 mmol/mol).[38] However, recent international substantial progress was observed between 2013 and 2022, with mean HbA1c declining from 8.2% (66.5 mmol/mol) to 7.6% (59.4 mmol/mol), particularly among younger individuals.[10]

In the Faroe Islands, 53% of individuals with HbA1c >7.4% (58 mmol/mol) did not use IPT. While this group did not show significantly worse outcomes compared to IPT users in this study, the relatively low uptake of IPT among individuals with suboptimal glycemic control may suggest opportunities to optimise treatment strategies. Potential factors influencing IPT use could include patient preferences, clinical decision-making, and eligibility criteria, though further research is needed to assess these aspects.

It is worth noting that the Faroese educational system is free of charge and provides financial support to students from the age of 18, both locally and abroad (primarily in Denmark). This structure has contributed to a relatively high level of educational attainment;

approximately 38% of adults aged 25-64 have completed tertiary education.[39] Such a context may support engagement with diabetes technologies, although individual-level education data were not available in this study.

Renal Function and IPT

Preserved renal function (eGFR ≥90 mL/min/1.73 m^2) was more frequently observed in IPT users, while reduced eGFR levels (<60 mL/min/1.73 m^2) was more common among MDI users. Maintaining renal function is essential for reducing cardiovascular risk, and these findings align with prior studies suggesting that AID systems may contribute to renal protection.[13,40]

Additionally, IPT users showed a greater percentage of normal ACR values, whereas MDI users displayed increased albuminuria. CGM data in other studies suggest that each 10% increase in TIR corresponds to a 19% reduction in UACR,[40] supporting the link between improved glycemic control and kidney health.[41] Reducing glycemic variability and fewer hyperglycemic episodes with IPT may lessen oxidative stress[42] and inflammation, drivers of diabetic nephropathy.[43]

Interestingly, the findings indicate that attaining an HbA1c level below 7% (53 mmol/mol) was not significantly linked to differences in ACR ($P = 0.82$). This supports the theory that HbA1c by itself might not be enough to represent renal risk, thereby suggesting that TIR might be a more accurate indicator.[40]

While these results suggest a potential protective effect of IPT on renal function, the observational nature of this study precludes causal inference. Additionally, renal function is affected by various factors beyond glycemic control, such as blood pressure regulation, lipid management, and the use of RAAS inhibitors. In this study, IPT users exhibited reduced rates of Grade 1 hypertension, yet demonstrated marginally elevated LDL levels, suggesting potential avenues for further optimization.

Longitudinal research is necessary to evaluate whether IPT directly protects against renal decline or if the observed benefits are mediated by broader metabolic improvements.

Clinical and Health Care Implications

Despite advanced technology use, glycemic control remained similar across treatment groups, supporting mixed evidence on IPT's effects on HbA1c. The high CGM adoption rate and strong IPT–CGM integration ($P < 0.001$) highlight the value of device compatibility. However, achieving optimal glycemic control requires comprehensive, individualized care, including education and behavioral support.

Hospital admission rates were similar for users of IPT and MDI. Approximately 50% of participants experienced more than 3 admissions in the past decade, indicating a significant health care burden associated with T1D and highlighting the necessity for strategies that address both clinical and social determinants of health.

Strengths and Limitations of This Study

This study's nationwide design and detailed dataset are strengths, offering insights into glycemic control, renal health, and health care utilization. A key strength of this study is the comprehensive inclusion of all adults with T1D residing in the Faroe Islands, enabled using a national EMR system linked to a unique personal identifier (p-tal) issued to all legal residents. This ensures accurate identification of the population and minimizes the risk of including nonresidents or transient visitors. All healthcare providers in the Faroe Islands use a centralized EMR system that integrates data across primary and secondary care, ensuring complete capture of individuals receiving insulin treatment. Limitations include missing data (addressed via imputation), exclusion of individuals with newly diagnosed T1D (<1 year), and lack of TIR data, which may provide a more comprehensive assessment of glycemic control.[24] As TIR is not currently recorded in the electronic medical records used for this study, these data were unavailable. However, efforts are ongoing to enable access to CGM-derived metrics through collaboration with the *StenoPool* data platform, which may facilitate the incorporation of TIR in future analyses.

While the use of EMR data may introduce selection bias, this risk is likely reduced in the Faroese setting, where all individuals with T1D are offered free outpatient care at the national diabetes center. Furthermore, the unified EMR system across primary and secondary care ensures that individuals receiving insulin, whether through specialist or general practice, are captured in the dataset. Due to the cross-sectional design, baseline data on HbA1c and renal function prior to IPT initiation were not available, limiting our ability to assess whether differences in outcomes reflect pre-existing differences between treatment groups. The absence of individual educational-level data also remains a limitation.

Furthermore, psychosocial factors, including social support and stress, were not assessed but may impact outcomes. Additional potential confounders comprise age, sex, adherence, comorbidities such as hypertension, hypercholesterolemia, and cardiovascular disease, as well as access to health care. These factors must be considered when interpreting results.

Finally, since this study captures a particular healthcare environment in the Faroe Islands, its results might not be applicable to other communities with different healthcare systems and patient demographics.

Conclusion

The prevalence of T1D among adults in the Faroe Islands (0.55%) is similar to that reported in other high-prevalence regions. More than 50% of individuals, particularly younger participants and those with longer T1D duration, used IPT, indicating that initiation often follows difficulties with MDI. Most participants used CGM, and 42% had HbA1c < 53 mmol/mol (7%).

Although IPT users demonstrated better renal function (lower ACR and higher eGFR), causality could not be established. Hospitalization rates and glycemic control were comparable between treatment groups, indicating that technology alone is insufficient to improve outcomes.

The proportion of participants reaching HbA1c targets indicates that recommended glycemic levels are achievable in the Faroe Islands, despite geographical challenges. These findings emphasize the importance of individualized care and equal access to diabetes technology, including in remote areas.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author used ChatGPT (OpenAI) to improve the clarity, grammar, and consistency of the English language. Following the use of this tool, the author carefully reviewed, edited, and verified the content to ensure accuracy and takes full responsibility for the final version of the manuscript.

Disclosure

The authors have no conflicts of interest to disclose.

Author Contributions

The Authors' contributions were as follows: H.L.J, J.A, and A.N. were involved in the conception of the study. H.L.J, J.A, M.S.P, A.N, R.F.B, and E.M.I contributed to the study's design and implementation and manuscript preparation. H.L.J, P.R, and R.F.B did the data analysis.

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