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RT-CGM in adults with type 1 diabetes improves both glycaemic and patient-reported outcomes, but independent of each other

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ABSTRACT

Aims: To examine in adults with type 1 diabetes (a) the effect of initiation of real-time continuous glucose monitoring (RT-CGM) on glycaemic and patient-reported outcomes (PROs), and (b) factors related to clinically relevant improvements and sustained device use.
Methods: 60 persons initiating RT-CGM completed questionnaires at device start and six months later. Demographics and clinical characteristics including (dis)continuation up until July 31st 2018 were obtained from medical records.
Results: After six months, 54 adults were still using RT-CGM. Short-term discontinuation (10%) was mainly related to end of pregnancy (wish). Longer-term discontinuation in those with an initial non-pregnancy indication was related to changes in the medical condition and behavioural/psychological reasons. After six months, $HbA_{1c,}$ diabetes-specific worries and self-efficacy improved (range $d = |0.4|–|0.8|$), while hypoglycaemia rate or awareness and more general distress did not change. More suboptimal scores at baseline were related to meaningful improvements in HbA_{1c} (≥10 mmol/mol; 0.9%) and PROs (≥0.5 SD). Changes in glycaemic variables and PROs were not related.
Conclusions: People with more suboptimal HbA_{1c} and PRO values appear to benefit most from RT-CGM. Given the lack of association between improvements in medical outcomes and PROs, both should be included in evaluations of RT-CGM therapy on an individual level.

1. Introduction

In people with type 1 diabetes, intensive insulin therapy with multiple daily injections or insulin pump reduces the risk of vascular complications [1]. However, only 20–30% of this group reaches the HbA_{1c} target of <53 mmol/mol (7%), with hypoglycaemia remaining the main limiting factor in glycaemic management [2,3]. Real-time continuous glucose

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monitoring (RT-CGM) offers the possibility for closer monitoring of glucose values and adjustment of therapy. Several randomised controlled trials have found RT-CGM to improve HbA_{1c} and/or reduce glucose variability, as compared to conventional self-monitoring of blood glucose, irrespective of insulin regimen [4,5]. In a randomised crossover trial among adults with impaired awareness of hypoglycaemia (IAH), RT-CGM also reduced the number of severe hypoglycaemic events compared to self-monitoring of blood glucose [6].

Remarkably, despite clear glycaemic benefits, data from the T1D Exchange clinic registry showed a rather high one-year discontinuation rate of 41% [7]. This raises questions about the effect of RT-CGM on patient-reported outcomes (PROs). Ideally, one would expect RT-CGM associated benefits in glycaemic outcomes to translate into improvement in PROs [8]. A handful of RT-CGM trials have included PROs as secondary outcome, mostly sparse, and have found some advantages in terms of quality of life, diabetes distress and fear of hypoglycaemia [6,8–12]. These findings are confirmed and supplemented by observational and qualitative data, suggesting that RT-CGM use can enhance confidence and sense of control and reduce diabetes-specific and more general distress and worries about hypoglycaemia [13–17]. At the same time, RT-CGM has also been associated with negative experiences due to the overwhelming amount of data, the disruptiveness of alarms, and physical discomfort [13–15]. It remains unclear whether improvements in glycaemic outcomes and PROs occur in parallel on the individual level, as previous studies have focused on group level changes. Furthermore, the interaction between person and technology in terms of RT-CGM uptake and success has not been comprehensively studied. It is known from the literature that there are systematic individual differences in technology acceptance and risk of information overload based on processing capacity and the five-factor model of personality traits [18–20].

To address these issues in a real-world setting, we aimed to examine the effect of RT-CGM use *on* and mutual associations *between* glycaemic outcomes (HbA_{1c}, severe hypoglycaemic events, hypoglycaemia awareness state) and PROs (diabetes-specific distress, worries about hypoglycaemia, diabetes-self-efficacy, and symptoms of depression and anxiety) in adults with type 1 diabetes. We also wanted to elucidate the demographic, clinical and psychosocial factors (in particular personality traits, coping style, symptom severity and history of mental health problems) that determined sustained RT-CGM use and success of treatment, as reflected by improvement in glycaemic and patient-reported parameters.

2. Subjects, materials and methods

2.1. Participants and procedure

This was a single-center study involving 60 adults with type 1 diabetes who initiated RT-CGM in accordance with Dutch regulations for reimbursement between October 2011 and September 2016. Eligibility criteria for starting RT-CGM included $HbA_{1c} > 64$ mmol/mol (8.0%) despite "maximal" treatment, pregnancy/pregnancy wish (i.e. intending to become pregnant), or frequent severe hypoglycaemia in the presence of IAH. Participants were sent a link to complete questionnaires online just before device start (baseline) and six months later. Follow-up questionnaire data were available for 35 persons (n = 37 for Hospital Anxiety and Depression Scale). The medical records of participants who initially started RT-CGM due to reasons other than pregnancy (or intended pregnancy) and were still using RT-CGM at six months follow-up were examined up to July 31st 2018 in order to establish whether people had stopped RT-CGM in the longer-term. As all data collection was part of regular care procedures, assessment by the hospital's medical ethics committee was waived.

2.2. Assessments

Details about the questionnaires and medical record data are provided in Table 1.

2.3. Statistical analyses

All analyses were conducted using IBM SPSS Statistics version 25, using $\alpha = 0.05$. Data are shown as mean ± SD, unless otherwise specified. Independent samples t-tests and X^2 tests were used to compare (a) those who still used RT-CGM at 6 months follow-up and those who had stopped; (b) the longer-term stop group and the group who continued RT-CGM; (c) the group who improved meaningfully (as defined by an HbA_{1c} decrease of $\geq$10 mmol/mol (0.9%) or an improvement in PROs of $\geq$0.5 SD [11]) and the remaining group (small improvement, no change, worsening) on demographic, clinical and psychological baseline characteristics. Hedges' g was calculated as an effect size statistic for continuous variables, with values of 0.2, 0.5 and 0.8 considered small, medium, and large, respectively. To examine changes in outcomes between baseline and 6 months follow-up, we used paired t-tests (with $d_{Repeated\ Measures}$ as effect size; similar interpretation as Hedges' g) and the McNemar(-Bowker) test. We also examined whether people with a history of mental health problems improved less than those without such a history, running independent samples t-tests and X^2 tests on change scores and ANCOVAs to control for baseline scores of the outcome in question. To examine whether change in one outcome parameter over the 6 months follow-up was related to change in other outcome parameters, we ran a correlation matrix (Pearson's r) for all outcome parameter change scores. As results from the pregnancy indication group were similar to the other indication groups, combined results are presented.

3. Results

3.1. Sample characteristics

Fig. 1 provides a flowchart of RT-CGM use and discontinuation in the study sample across the study period. The total sample included 60 adults (80% female), with a mean age of 38 ± 11 years, diabetes duration of 23 ± 11 years, and HbA_{1c} of 67 ± 11 mmol/mol (8.3 ± 1.0%). At least one severe hypoglycaemic event in the previous six months was reported by

Table 1 – Overview of study measures.

Construct	Source	Items	Scale	Score range	Interpretation	Key reference
Diabetes-specific distress	Problem Areas in Diabetes (PAID) questionnaire	20	5-point Likert, 0 "Not a problem" – 4 "A serious problem"	0–100 (after transformation)	Higher scores indicate higher distress	Snoek et al. Diabetes-related emotional distress in Dutch and U.S. diabetic patients: cross-cultural validity of the problem areas in diabetes scale. Diabetes Care. 2000;23 (9):1305–9
Worries about hypoglycaemia	Hypoglycaemia Fear Survey – worries subscale (HFS-W)	13	5-point Likert, 0 "Never" – 4 "Very often"	0–52	Higher scores indicate higher worries	Cox et al. Fear of hypoglycemia: quantification, validation, and utilization. Diabetes Care. 1987;10(5):617–21
Diabetes-specific self-efficacy	Confidence in Diabetes Self-Care (CIDS)	20	5-point Likert, 1 "No, I am sure I cannot" 5 "Yes, I am sure I can"	20–100 (untransformed)	Higher scores indicate higher self-efficacy	Van der Ven et al. The confidence in diabetes self-care scale: psychometric properties of a new measure of diabetes-specific self-efficacy in Dutch and US patients with type 1 diabetes. Diabetes Care. 2003;26(3):713–8
Sensor-specific self-efficacy	Confidence in Diabetes Self-Care sensor subscale (CIDS-s)	8	5-point Likert, 1 "No, I am sure I cannot" 5 "Yes, I am sure I can"	8–40 (untransformed)	Higher scores indicate higher self-efficacy	Created by the authors, based on summing the scores of CIDS items expected to be influenced by RT-CGM use (2, 4–9, 13). Cronbach's alpha = 0.71 at baseline, 0.86 at follow-up
Past week symptoms of depression	Hospital Anxiety and Depression Scale – depression (HADS-D)	7	4-point Likert, 0 "Not at all" 3 "Most of the time" (or similar)	0–21	Higher scores indicate higher symptom levels	Zigmond & Snaith. The hospital anxiety and depression scale. Acta Psychiatr Scand. 1983;67(6):361–70
Past week symptoms of anxiety	Hospital Anxiety and Depression Scale – anxiety (HADS-A)	7	4-point Likert, 0 "Not at all" 3 "Most of the time" (or similar)	0–21	Higher scores indicate higher symptom levels	Zigmond & Snaith. The hospital anxiety and depression scale. Acta Psychiatr Scand. 1983;67(6):361–70
Personality traits	Big Five Inventory (BFI): Openness Conscientiousness Extraversion Agreeableness Neuroticism	10 9 8 9 8	5-point Likert, 1 "Disagree strongly" 5 "Agree strongly"	1–5 (after reverse scoring negatively keyed items and averaging items for each trait)	Higher scores indicate higher trait levels	John et al. Paradigm shift to the integrative Big Five trait taxonomy: History, measurement, and conceptual issues. In: John OP, Robins RW, Pervin LA, editors. Handbook of personality: Theory and research (3rd ed.). New York: Guilford Press; 2008. p. 114–58
Coping styles	Coping Inventory for Stressful Situations (CISS): Task-oriented Emotion-oriented Avoidance-oriented	16 16 16	5-point Likert, 1 "Not at all" 5 "Very much"	16–80	Higher scores indicate higher level of coping style	Endler & Parker. Multidimensional assessment of coping: a critical evaluation. J Pers Soc Psychol. 1990;58(5):844–54
Severe hypoglycaemic events in previous six months	Modified Clarke method[a]	1	5-point Likert, 1 "Never" - "5 More than once per month"	1–5	Higher scores indicate more frequent events	Clarke et al. Reduced awareness of hypoglycemia in adults with IDDM. A prospective study of hypoglycemic frequency and associated symptoms. Diabetes Care. 1995;18(4):517–22
Impaired awareness of hypoglycaemia	Modified Clarke method [b]	1	"No" or "Yes"		"Yes" indicates problems	Janssen et al. Assessing impaired hypoglycemia awareness in type 1 diabetes: agreement of self-report but not of field study data with the autonomic symptom threshold during experimental hypoglycemia. Diabetes Care. 2000;23(4):529–32
History of mental health problems	Study-specific question [c]	1	"No" or "Yes"		"Yes" indicates problems	
Gender	Medical record					
Age	Medical record					
Diabetes duration	Medical record					
HbA_{1c}	Medical record					

[a] Combination of Clarke's definition of "moderately severe events" (needing help by another person) and "severe events" (needing medical intervention), where for "severe events" never = never, 1–2 times = once or twice, 3–4 times = once per two months, 5–6 times = once per month, 7 times and up = more than once per month; [b] dichotomized as "always" = no impaired awareness and "sometimes" and "never" = impaired awareness; [c] eating problems, alcohol problems, anxiety or depressive symptoms, or other mental health problems.

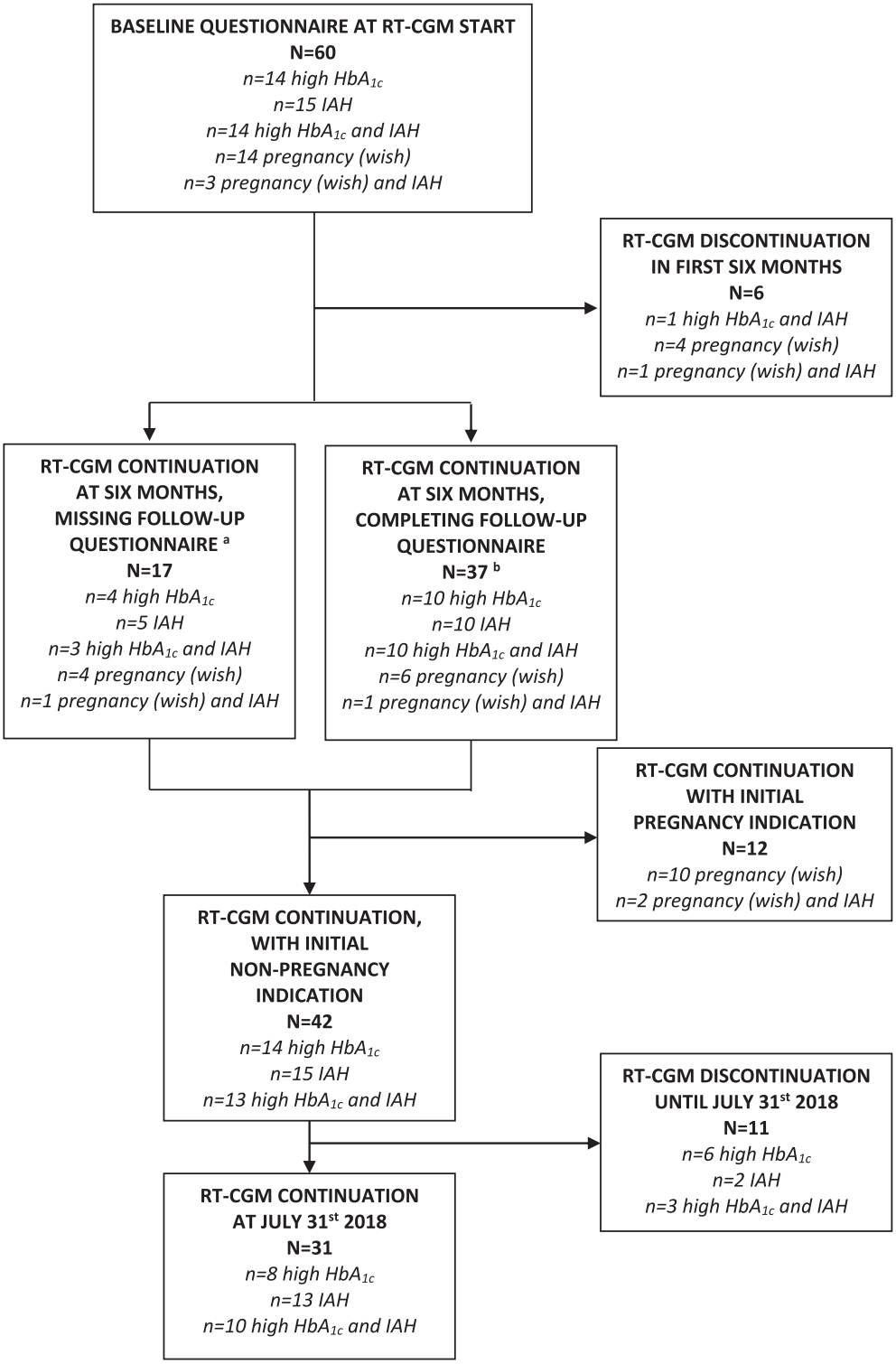

Fig. 1 – Flowchart of RT-CGM use and discontinuation among adults with type 1 diabetes in regular care across the study period, including initial RT-CGM indication. IAH = impaired awareness of hypoglycaemia; [a] HbA_{1c} at six months available from medical records for all 60 participants; [b] two of the 37 people completing follow-up questionnaires at six months only completed HADS-D and HADS-A.

38 persons (63%), 22 of whom had needed medical intervention at least once. The criteria for IAH (Table 1) were fulfilled by 38 persons (63%), of whom 2 reported severe unawareness (i.e., never noticing low blood glucose levels). RT-CGM indications included high HbA_{1c} for 14 people (23%), IAH for 15 (25%), a combination of high HbA_{1c} and IAH for 14 (23%), pregnancy (wish) for 14 (23%), and a combination of pregnancy (wish) and IAH for 3 (5%).

3.2. RT-CGM discontinuation within six months

After six months, 54 people (90%) were still using the sensor. Except for one person who discontinued because of system inconvenience, all other five persons who discontinued RT-CGM did so because of pregnancy completions (which terminated sensor reimbursement). Differences between those who continued and those who discontinued RT-CGM (younger age, shorter diabetes duration, lower HbA_{1c}) could be traced back to pregnancy.

3.3. RT-CGM discontinuation after six months

Among those who initially started RT-CGM for a non-pregnancy related indication and were still using it at 6 months follow-up (n = 42), there were an additional 11 people who discontinued RT-CGM over a mean follow-up period of 4.88 ± 1.67 years (range 2–7). Reasons for stopping included end of a later pregnancy (n = 3), infrequent RT-CGM use (n = 2), pancreas and kidney transplantation (n = 1), too much sensor-related stress (n = 4), and psychiatric problems (n = 1). One of these persons also reported that the sensor adhesive came off prematurely. Two participants died while on RT-CGM, but neither death was related to the use of RT-CGM or glucose control; in the present analyses, both individuals were considered to have continued RT-CGM. In the total group with an initial non-pregnancy related indication (n = 43), no significant differences in baseline characteristics were found when comparing the 12 participants who discontinued RT-CGM over the entire study period with the 31 ongoing users.

3.4. Glycaemic outcomes

In the group of 54 ongoing sensor users, HbA_{1c} decreased from 68 ± 11 mmol/mol (8.4 ± 1.0%) at baseline to 61 ± 10 mmol/mol (7.7 ± 0.9%) at 6 months follow-up ($t(53) = 6$, $p < 0.001$, $d = -0.8$), whereas HbA_{1c} did not meaningfully change in the 6 persons who discontinued RT-CGM. Of the 41 continued sensor users whose HbA_{1c} decreased, 26 (63%) had hypoglycaemia data available at follow-up; three (12%) reported an increase in severe hypoglycaemic events and three (12%) a worsening in IAH. Overall, there was no statistically significant change in the proportion of severe hypoglycaemic events ($p = 0.11$) or IAH ($p = 0.38$) from baseline to 6 months follow-up. In those with a RT-CGM indication related to problematic hypoglycaemia (including IAH) and

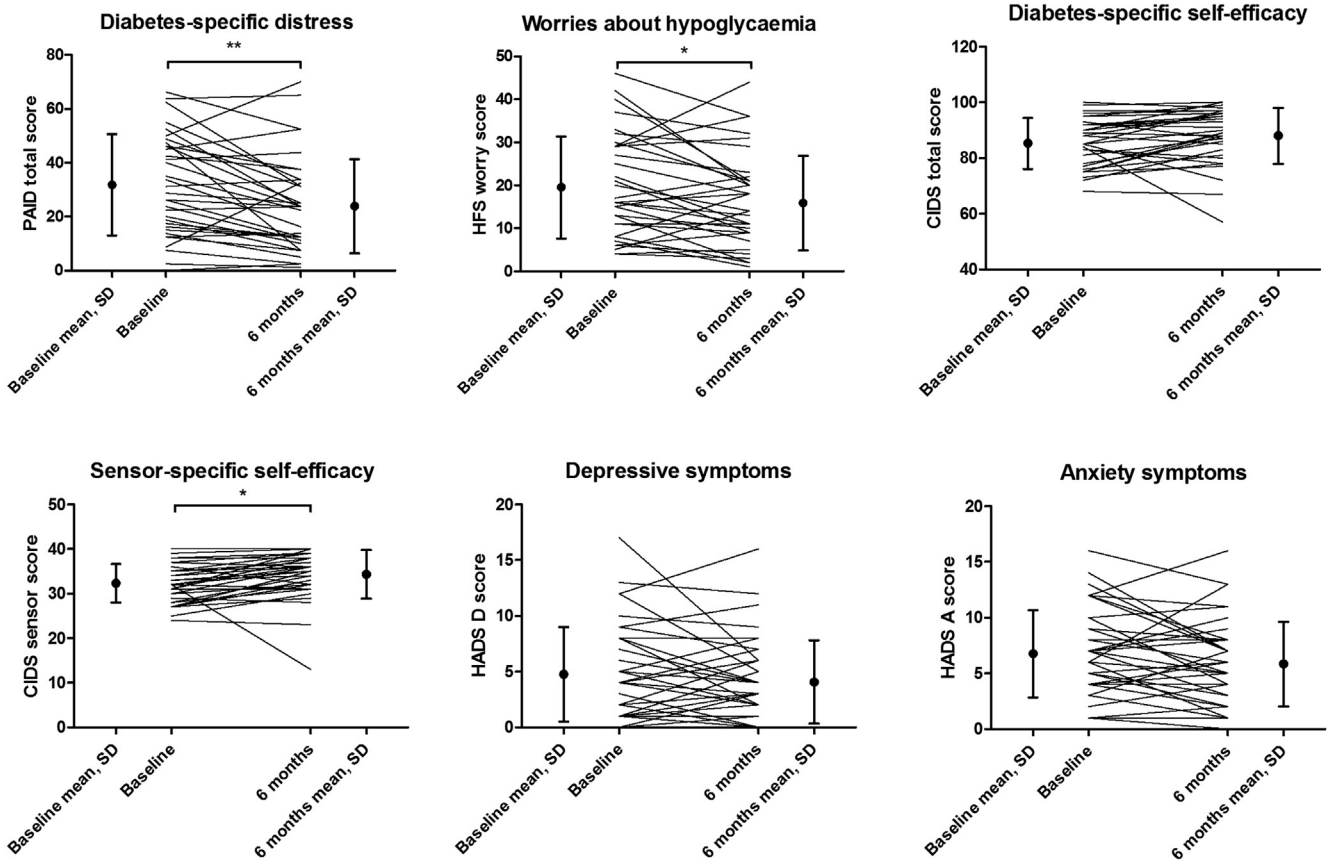

Fig. 2 – Changes in PRO scores from baseline to 6 months follow-up. X-axis represents (from left to right) group mean ± SD of baseline score, baseline score for individuals, 6 months follow-up score for individuals, and group mean ± SD of 6 months follow-up score. Y-axis represents (from left to right and top to bottom) scores on PAID, HFS worry, CIDS total, CIDS sensor, HADS depression, HADS anxiety; higher scores are more suboptimal (except for CIDS total and CIDS sensor, where lower scores are more suboptimal). Significance testing represents the results of paired samples t-tests using baseline and 6 months follow-up scores; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

hypoglycaemia data available at follow-up (n = 20), nine persons (45%) improved with respect to severe events and one person (5%) with respect to IAH.

3.5. PROs

PRO scores at baseline and 6 months follow-up are shown in Fig. 2. There was a significant decrease in diabetes-specific worries ($t[34] = 3$, $p = 0.002$, $d = -0.6$) and worries about hypoglycaemia ($t[34] = 2$, $p = 0.02$, $d = -0.4$), and an increase in sensor-specific self-efficacy ($t[34] = -2$, $p = 0.03$, $d = 0.5$).

3.6. Predictors of clinically relevant improvement

Participants with a ≥10 mmol/mol (0.9%) improvement in HbA_{1c} had a lower conscientiousness score ($g = -0.6$) and higher HbA_{1c} at baseline ($g = 0.7$), were more likely to have IAH and worried more about hypoglycaemia ($g = 0.9$) than those who showed less improvement (Table 2). Those with meaningful improvement on a given PRO had a more suboptimal baseline score on that particular PRO than those with less improvement. With respect to other more general trends, higher emotion-focused coping at baseline distinguished those with meaningful improvement for half of the PROs (PAID $g = 0.9$, CIDS-t $g = 0.9$ and HADSA $g = 0.9$), as did higher anxiety symptoms (PAID $g = 0.7$, CIDS-t $g = 0.8$ and CIDS-s $g = 1.3$). Concerning the PROs, personality traits were only relevant for improvement in CIDS-t (agreeableness $g = -0.8$) and HADSA (neuroticism $g = 0.9$). None of the clinical variables were related to meaningful PRO change, except a higher baseline prevalence of IAH in those improving with respect to the HFS.

3.7. History of mental health problems

In total, 29 (48%) of the participants reported a history of mental health problems. This group showed more improvement with respect to the PAID (-14 ± 12 versus -2 ± 11, $p = 0.004$, $g = -1.1$), CIDS-t (5 ± 6 versus -1 ± 8, $p = 0.04$, $g = 0.7$) and HADS-A (-2 ± 3 versus 0 ± 3, $p = 0.03$, $g = -0.8$) than those without such a history. However, these differences disappeared after controlling for baseline scores of the outcome in question, except for the higher PAID improvement (estimated marginal mean ± standard error -12 ± 3 versus -3 ± 3, $p = 0.04$, partial eta squared = 0.12). The two groups did not differ with respect to changes in glycaemic parameters.

3.8. Correlations between change scores

An improvement in diabetes-specific distress was associated with improvements in worries about hypoglycaemia, general diabetes self-efficacy, and general anxiety (Table 3). An improvement in general anxiety was also associated with an improvement in general and sensor-specific diabetes self-efficacy and in depressive symptoms. Glycaemic improvements were not significantly associated with a change in any of the other clinical or psychological outcomes.

4. Discussion

These real-world findings show that RT-CGM in adults with type 1 diabetes has benefits both in terms of HbA_{1c} and PROs, while the rate of severe hypoglycaemic events or awareness of hypoglycaemia did not change. These improvements were not interrelated, but baseline lower conscientiousness score and higher worries about hypoglycaemia did predict clinically meaningful improvement in HbA_{1c}. Meaningful improvement in PROs was consistently predicted by higher baseline scores on these measures. Despite group level improvements, about one in four persons stopped using RT-CGM over a mean follow-up period of five years. Short-term discontinuation of RT-CGM was almost exclusively related to its use in the context of pregnancy and the consequent termination of reimbursement eligibility after giving birth.

In line with previous randomised trials, RT-CGM use in a real-world setting (including pregnancy and non-pregnancy indications) was related to a significant reduction in HbA_{1c} [4] and did not lead to improvements in awareness of hypoglycaemia [6]. In contrast to some trial data [6], RT-CGM was not related to a lower number of severe hypoglycaemic events. Accuracy in the hypoglycaemic range remains an important weakness of most RT-CGM devices, certainly in the past [21].

The pattern of PRO improvement is in line with previous findings of RT-CGM contributing to diabetes-specific but not to more general psychological measures [12], although positive results for more general emotional well-being have also been reported [9]. Compared with studies examining similar measures in people on multiple daily injections [9,12], the effect size for measures of diabetes-distress and confidence was somewhat stronger in our sample on pump therapy. We speculate that pump users are more technology oriented and better prepared for the increase in information and actions CGM technology brings, while this increase is more likely to be perceived as overwhelming in individuals on injection therapy. People with more suboptimal PROs at baseline were most likely to benefit from RT-CGM use (the same pattern was found for HbA_{1c}). This could indicate regression to the mean, but may also suggest that psychological problems or vulnerabilities are not by definition a contraindication for RT-CGM start [22].

Participants in whom RT-CGM was associated with a meaningful HbA_{1c} improvement had more worries about hypoglycaemia at study start. It could be hypothesised that fear of hypoglycaemia was a particular barrier to optimizing glucose control in these people that CGM was able to eliminate. We also found that emotion-focused coping and lower conscientiousness were positively related to some aspects of CGM success. This contrasts earlier qualitative findings suggesting RT-CGM “non-responders” have an emotion-based coping style and get frustrated, while “responders” have a self-controlled coping style, can problem-solve issues, and review data to identify patterns [23]. Those who already displayed more task-focused behaviour may have had less to gain from RT-CGM or could have found it difficult to deal with the reality of low or high glucose values even when using

Table 2 – Comparison of baseline characteristics between the group with a meaningful HbA_{1c} or PRO improvement over the study period [a] and the group who improved less, stayed the same, or deteriorated.

	HbA_{1c}		Diabetes-specific worries		Worries about hypoglycaemia		Diabetes-specific self-efficacy		Sensor-specific self-efficacy		Depressive symptoms		Anxiety symptoms	
	+/=/− n = 36	++ n = 18	+/=/− n = 21	++ n = 14	+/=/− n = 22	++ n = 13	+/=/− n = 22	++ n = 13	+/=/− n = 22	++ n = 13	+/=/− n = 29	++ n = 8	+/=/− n = 26	++ n = 11
Female gender	83 (30)	67 (12)	76(16)	86(12)	82(18)	77(10)	77(17)	85(11)	77(17)	85(11)	76(22)	88(7)	81(21)	73(8)
Age, years	39 ± 12	38 ± 10	41 ± 11	39 ± 12	41 ± 11	39 ± 13	39 ± 12	42 ± 12	40 ± 11	40 ± 13	41 ± 13	41 ± 8	40 ± 13	43 ± 8
Diabetes duration, years	25 ± 11	22 ± 10	25 ± 10	22 ± 12	23 ± 10	24 ± 12	23 ± 10	24 ± 12	24 ± 10	23 ± 13	23 ± 11	27 ± 7	22 ± 10	29 ± 10
Openness	3 ± 1	3 ± 1	4 ± 0	4 ± 1	4 ± 0	3 ± 1	4 ± 0	4 ± 1	3 ± 1	4 ± 0	3 ± 0	4 ± 1	3 ± 1	4 ± 0
Conscientiousness	***4 ± 1***	***3 ± 1***	4 ± 0	3 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1
Extraversion	4 ± 1	3 ± 1	4 ± 1	3 ± 1	3 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	4 ± 1	3 ± 1	4 ± 1	4 ± 1	3 ± 1
Agreeableness	4 ± 0	4 ± 1	4 ± 0	4 ± 0	4 ± 0	4 ± 0	***4 ± 0***	***4 ± 0***	4 ± 0	4 ± 0	4 ± 0	4 ± 0	4 ± 0	4 ± 0
Neuroticism	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	***3 ± 1***	***3 ± 1***
Task focused coping	58 ± 10	53 ± 11	57 ± 10	58 ± 10	58 ± 11	57 ± 10	56 ± 11	61 ± 8	57 ± 7	59 ± 14	59 ± 9	55 ± 13	58 ± 8	59 ± 14
Emotion focused coping	36 ± 12	40 ± 14	***31 ± 10***	***41 ± 13***	34 ± 12	37 ± 12	***32 ± 10***	***41 ± 12***	33 ± 11	40 ± 13	33 ± 12	42 ± 9	***32 ± 10***	***42 ± 13***
Avoidance coping	43 ± 9	43 ± 13	***40 ± 10***	***49 ± 11***	42 ± 10	47 ± 12	42 ± 11	47 ± 11	44 ± 11	44 ± 11	43 ± 11	46 ± 11	45 ± 11	41 ± 11
Most recent HbA_{1c} mmol/mol	***66 ± 9***	***73 ± 13***	69 ± 13	71 ± 9	70 ± 13	71 ± 10	68 ± 9	73 ± 15	71 ± 13	69 ± 10	70 ± 12	69 ± 8	70 ± 12	71 ± 11
≥1 severe hypoglycaemic event	58 (21)	78 (14)	62 (13)	64 (9)	59 (13)	69 (9)	59 (13)	69 (9)	55 (12)	77 (10)	69 (20)	50 (4)	62 (16)	73 (8)
Impaired hypoglycaemia awareness	***50 (18)***	***83 (15)***	48 (10)	64 (9)	***41 (9)***	***77 (10)***	45 (10)	69 (9)	50 (11)	62 (8)	55 (16)	63 (5)	54 (14)	64 (7)
Diabetes-specific worries	33 ± 19	36 ± 21	***25 ± 17***	***41 ± 15***	31 ± 18	31 ± 19	27 ± 18	39 ± 18	27 ± 19	39 ± 16	31 ± 20	34 ± 13	31 ± 20	35 ± 17
Worries about hypoglycaemia	***16 ± 10***	***26 ± 12***	18 ± 11	21 ± 14	***16 ± 10***	***25 ± 13***	17 ± 10	23 ± 14	18 ± 10	22 ± 15	19 ± 12	20 ± 11	19 ± 11	21 ± 14
Diabetes-specific self-efficacy	85 ± 9	81 ± 12	***89 ± 8***	***81 ± 8***	88 ± 8	83 ± 10	***89 ± 8***	***80 ± 6***	***89 ± 9***	***81 ± 7***	86 ± 9	81 ± 9	86 ± 9	83 ± 9
Sensor-specific self-efficacy	33 ± 4	32 ± 5	***34 ± 4***	***30 ± 4***	33 ± 4	32 ± 5	***34 ± 4***	***30 ± 3***	***34 ± 4***	***30 ± 3***	33 ± 4	30 ± 4	33 ± 4	31 ± 4
Depressive symptoms	5 ± 4	5 ± 4	4 ± 4	5 ± 5	5 ± 5	3 ± 3	4 ± 3	6 ± 5	4 ± 3	6 ± 5	***4 ± 4***	***8 ± 5***	4 ± 4	6 ± 6
Anxiety symptoms	7 ± 4	8 ± 5	***6 ± 4***	***8 ± 4***	7 ± 4	6 ± 4	***6 ± 4***	***9 ± 4***	***5 ± 3***	***9 ± 4***	6 ± 4	9 ± 4	***5 ± 3***	***10 ± 4***

Values are % (n) or mean ± SD; bold italic: statistically significant difference between both groups, $p < 0.05$; +/=/−: minimal improvement, no change, deterioration; ++: meaningful change.

[a] HbA_{1c} improvement based on change score <10 mmol/mol versus ≥10 mmol/mol; PRO improvement based on change score <0.5 SD baseline measure versus ≥ 0.5 SD baseline measure.

Table 3 – Correlation matrix of outcome change scores.

		1	2	3	4	5	6	7	8	9
1	HbA_{1c} level	1								
2	Severe events per person	−0.07	1							
3	Impaired hypoglycaemia awareness	−0.04	0.16	1						
4	Diabetes-specific worries	0.18	0.01	0.14	1					
5	Worries about hypoglycaemia	0.15	−0.04	0.12	***0.52***	1				
6	Diabetes-specific self-efficacy	−0.09	−0.01	−0.01	***−0.39***	−0.07	1			
7	Sensor-specific self-efficacy	0.03	0.02	−0.02	−0.25	−0.06	***0.90***	1		
8	Depressive symptoms	−0.10	0.33	0.03	0.13	−0.29	−0.24	−0.10	1	
9	Anxiety symptoms	0.20	0.03	−0.02	***0.46***	0.14	***−0.67***	***−0.55***	***0.43***	1

Values are Pearson's correlations between dyads of change scores. Change scores represent follow-up score minus baseline score. A change score <0 indicates improvement, 0 no change, and >0 deterioration, except for the self-efficacy variables where change score <0 indicates deterioration, 0 no change, and >0 improvement. Bold italic: statistically significant correlation, $p < 0.05$.

RT-CGM [15]. More research is needed to better understand who is likely to have negative experiences with RT-CGM use, and whether these disadvantages can be avoided by providing additional support.

The RT-CGM discontinuation rates of the present study are considerably lower than the one-year rate of 41% reported by participants in the T1D Exchange clinic registry [7]. This difference is likely due to temporary periods of RT-CGM discontinuation in the US study in which costs, discomfort and device intrusiveness figured prominently among the reasons for stopping [7,24]. While the stressfulness of using the device was also regularly documented in Dutch medical records, reasons for stopping in the present study also included physician-initiated judgments on necessity and appropriateness of continued use (in particular in case of pregnancy end).

People's psychological profile, including their personality, did not predict RT-CGM (dis)continuation. The links between personality and acceptance/use of technology differ depending on the technology in question [18,19], but we would have expected to find for example that sustained RT-CGM use was more likely in people with high conscientiousness (representing their intrinsic motivation for improvement) and low neuroticism (representing better stress regulation). However, there may have been a regular care selection bias limiting the score range, in that personality characteristics thought to have a high potential for RT-CGM discontinuation could have been reason for diabetes teams to not consider RT-CGM. Alternatively, availability of specialized nurse practitioners for adjustments and trouble shooting and a clinical psychologist for psychological support may have facilitated continued use [25].

The lack of relation between improvements in glycaemic outcomes and PROs weakens the hypothesis that psychosocial benefits of RT-CGM are (at least partially) due to improvements in HbA_{1c} and time spent in hypoglycaemia [9]. A stable balance between optimal glycaemic outcomes and emotional well-being seems difficult to achieve [26], poising between a fear of hypoglycaemia in the short term and a fear of complications in the future. This underlines the necessity of including both medical outcomes and PROs in evaluations of RT-CGM therapy, and to also analyze data on an individual level to see where additional support is needed.

Strengths of the study include the simultaneous focus on both use and effectiveness of RT-CGM, the measurement of a broad set of PROs and person characteristics using validated questionnaires, and a first initiative to come to a broader framework for understanding the interaction between a person's psychological profile and technology uptake/success. Limitations also need to be acknowledged. Our sample was relatively small and included mostly female adults with T1D from a single hospital in the Dutch health care setting with strict reimbursement pressures, which limits generalizability. Furthermore, the increased potential for type 1 errors with multiple testing should be kept in mind.

In summary, in a real-world setting we found that adults with type 1 diabetes having more suboptimal HbA_{1c} values, lower conscientiousness scores and higher worries about hypoglycaemia benefited most from RT-CGM use with respect to HbA_{1c}; suboptimal PRO values were consistently related to larger improvements in PROs. There was no association between improvements in medical outcomes and PROs. We therefore propose that both should be included in evaluations of RT-CGM therapy to better appreciate its effectiveness on an individual level and encourage future studies that further clarify the interaction between person and technological device.

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Declarations of Competing Interest

None.

Author contributions

GN drafted the manuscript and researched data;

EB conceived the study, researched data, and reviewed/edited the manuscript;

DM researched data, and reviewed/edited the manuscript;

NS researched data, and reviewed/edited the manuscript;

CJT conceived the study, researched data, and reviewed/edited the manuscript;

BEDG conceived the study, researched data, and reviewed/edited the manuscript;

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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. Diab Care 2014;37:9–16.
[2] Miller KM, Foster NC, Beck RW, Bergenstal RM, DuBose SN, DiMeglio LA, et al. Current state of type 1 diabetes treatment in the U.S.: updated data from the T1D Exchange clinic registry. Diab Care 2015;38:971–8.
[3] International Hypoglycaemia Study Group. Minimizing hypoglycemia in diabetes. Diab Care 2015;38:1583–91.
[4] Slattery D, Choudhary P. Clinical use of continuous glucose monitoring in adults with type 1 diabetes. Diab Technol Ther 2017;19:S55–61.
[5] El-Laboudi AH, Godsland IF, Johnston DG, Oliver NS. Measures of glycemic variability in type 1 diabetes and the effect of real-time continuous glucose monitoring. Diab Technol Ther 2016;18:806–12.
[6] van Beers CA, DeVries JH, Kleijer SJ, Smits MM, Geelhoed-Duijvestijn PH, Kramer MH, et al. Continuous glucose monitoring for patients with type 1 diabetes and impaired awareness of hypoglycaemia (IN CONTROL): a randomised, open-label, crossover trial. Lancet Diab Endocrinol 2016;4:893–902.
[7] Wong JC, Foster NC, Maahs DM, Raghinaru D, Bergenstal RM, Ahmann AJ, et al. Real-time continuous glucose monitoring among participants in the T1D Exchange clinic registry. Diab Care 2014;37:2702–9.
[8] Rubin RR, Peyrot M. Patient-reported outcomes and diabetes technology: a systematic review of the literature. Pediatr Endocrinol Rev: PER 2010;7(Suppl 3):405–12.
[9] Lind M, Polonsky W, Hirsch IB, Heise T, Bolinder J, Dahlqvist S, et al. Continuous glucose monitoring vs conventional therapy for glycemic control in adults with type 1 diabetes treated with multiple daily insulin injections: the GOLD randomized clinical trial. JAMA 2017;317:379–87.
[10] Riveline JP, Schaepelynck P, Chaillous L, Renard E, Sola-Gazagnes A, Penfornis A, et al. Assessment of patient-led or physician-driven continuous glucose monitoring in patients with poorly controlled type 1 diabetes using basal-bolus insulin regimens: a 1-year multicenter study. Diab Care 2012;35:965–71.
[11] Peyrot M, Rubin RR. Patient-reported outcomes for an integrated real-time continuous glucose monitoring/insulin pump system. Diab Technol Ther 2009;11:57–62.
[12] Polonsky WH, Hessler D, Ruedy KJBeck Group DS. The impact of continuous glucose monitoring on markers of quality of life in adults with type 1 diabetes: further findings from the DIAMOND randomized clinical trial. Diab Care 2017;40:736–41.
[13] Polonsky WH, Hessler D. What are the quality of life-related benefits and losses associated with real-time continuous glucose monitoring? A survey of current users. Diab Technol Ther 2013;15:295–301.
[14] Anhalt H. Limitations of continuous glucose monitor usage. Diab Technol Ther 2016;18:115–7.
[15] Vloemans AF, van Beers CAJ, de Wit M, Cleijne W, Rondags SM, Geelhoed-Duijvestijn PH, et al. Keeping safe. Continuous glucose monitoring (CGM) in persons with Type 1 diabetes and impaired awareness of hypoglycaemia: a qualitative study. Diab Med 2017;34:1470–6.
[16] Litchman ML, Allen NA. Real-time continuous glucose monitoring facilitates feelings of safety in older adults with type 1 diabetes: a qualitative study. J Diab Sci Technol 2017;11:988–95.
[17] Pickup JC, Ford Holloway M, Samsi K. Real-time continuous glucose monitoring in type 1 diabetes: a qualitative framework analysis of patient narratives. Diab Care 2015;38:544–50.
[18] Devaraj S, Easley RF, Crant M. Research Note - How does personality matter? Relating the Five-Factor model to technology acceptance and use. Inform Syst Res 2008;19:93–105.
[19] Svendsen G, Johnsen J, Almas-Sorensen L, Vitterso J. Personality and technology acceptance: the influence of personality factors on the core constructs of the Technology Acceptance Model. Behav Inform Technol 2013;32:323–34.
[20] Jackson TW, Farzaneh P. Theory-based model of factors affecting information overload. Int J Inform Manage 2012;32:523–32.
[21] Moser O, Pandis M, Aberer F, Kojzar H, Hochfellner D, Elsayed H, et al. A head-to-head comparison of personal and professional continuous glucose monitoring systems in people with type 1 diabetes: hypoglycaemia remains the weak spot. Diab Obes Metab 2018.
[22] van Beers CAJ, de Wit M, Kleijer SJ, Geelhoed-Duijvestijn PH, DeVries JH, Kramer MHH, et al. Continuous glucose monitoring in patients with type 1 diabetes and impaired awareness of hypoglycemia: also effective in patients with psychological distress? Diab Technol Ther 2017;19:595–9.
[23] Ritholz MD, Atakov-Castillo A, Beste M, Beverly EA, Leighton A, Weinger K, et al. Psychosocial factors associated with use of continuous glucose monitoring. Diab Med 2010;27:1060–5.
[24] Tanenbaum ML, Hanes SJ, Miller KM, Naranjo D, Bensen R, Hood KK. Diabetes device use in adults with type 1 diabetes: barriers to uptake and potential intervention targets. Diab Care 2017;40:181–7.
[25] Franklin V. Influences on technology use and efficacy in type 1 diabetes. J Diab Sci Technol 2016;10:647–55.
[26] Bazelmans E, Netea-Maier RT, Vercoulen JH, Tack CJ. Surprisingly few psychological problems and diabetes-related distress in patients with poor glycaemic control. Netherlands J Med 2016;74:16–21.