Self-monitoring of blood glucose compared to self-monitoring of urine glucose in adults with newly diagnosed Type 2 diabetes receiving structured education: a cluster randomised controlled trial

Running title: Self-monitoring of blood glucose versus urine glucose

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Novelty statement

- This is the first pragmatic trial comparing blood glucose monitoring with urine glucose monitoring within an established and widely available structured education course.
- Equivalent improvements in HbA1c and other biomedical outcomes were seen regardless of the mode of monitoring, though participants showed a slight preference towards blood monitoring.

- Promoting urine monitoring as the method of choice in structured education programmes for the newly diagnosed might lead to substantial savings without impairing outcomes. However those who find blood monitoring more useful should be permitted to do so, but would need to be provided with support by their healthcare team.

Abstract

Aims: To compare the effectiveness and acceptability of self-monitoring of blood glucose and urine glucose in adults with newly diagnosed Type 2 diabetes.

Methods: Multi-site cluster randomised controlled trial with practice-level randomisation. Participants attended a group structured education programme which included a module on self-monitoring using blood glucose or urine glucose monitoring. HbA1c and other biomedical measures as well as psychosocial data were collected at 6, 12 and 18 months. A total of 292 people with Type 2 diabetes were recruited.

Results: HbA1c reduced significantly from baseline to 18 months in both the blood monitoring (-12mmol/mol [SE = 2mmol/mol]; -1.1% [SE = 0.2%]) and urine monitoring (-13mmol/mol [SE = 2mmol/mol]; -1.2% [SE = 0.2%]) groups, with no difference between groups (difference adjusted for cluster effect and baseline value = -1mmol/mol [95% CI = -3, 2]; -0.1% [95% CI = -0.3, 0.2]). Similar improvements were observed for the other biomedical outcomes, with no differences between groups. Both groups showed improvements in total treatment satisfaction, generic well-being, and diabetes-specific well-being, and a less threatening view of diabetes, with no differences between groups at 18 months. Approximately 1 in 5 participants in the urine monitoring arm switched to blood monitoring, while those in the blood monitoring arm rarely switched (18% vs 1% at 18 months; $p < 0.001$).

Conclusions: People with newly diagnosed Type 2 diabetes who attended structured education showed comparable improvements in HbA1c at 18

months, regardless of whether they were assigned to blood or urine self-monitoring.

Introduction

Self-monitoring of blood glucose is a core component of effective self-management of Type 1 diabetes, and of Type 2 diabetes for people using insulin or sulphonylureas[1,2]. However, the benefit is less clear for people with Type 2 diabetes using diet or oral agents that do not increase the risk of hypoglycaemia[3-7]. This lack of clarity is in part because the trials conducted are heterogeneous, differing in trial design, population recruited, and how the use of self-monitoring was implemented[3-7]. As a result, many propose that the evidence does not justify self-monitoring of blood glucose by people with non-insulin treated Type 2 diabetes, and that the costs saved could be redirected to evidence-based management strategies[8]. Others acknowledge that implementing self-monitoring in isolation without training of both patients and clinicians may waste resources but maintain that including it within a structured approach to management may be effective and clinically relevant [9,10].

Very few studies have examined self-monitoring of blood glucose in people with newly diagnosed Type 2 diabetes[11,12] or compared it with other forms of glucose monitoring (e.g. urine monitoring) which might be provided at less cost[13-15]. We hypothesised that for adults with newly diagnosed type 2 diabetes attending group structured education, use of self-monitoring of urine glucose would be as effective as blood glucose monitoring, in terms of improving and sustaining glycaemic control over 18 months. We tested this hypothesis within the context of the DESMOND (Diabetes Education Self-Management for Ongoing and Newly diagnosed Diabetes) structured

education programme[16]. The standard curriculum was modified with modules on the two methods of self-monitoring added, enabling comparison in a randomised controlled trial, while ensuring that both arms experienced comparable structured education in self-management.

Methods

The study design and protocol have been published elsewhere[17]. In brief, the study was an 18-month multi-site cluster-randomised controlled trial with practices randomised to one of two arms. All participants attended a DESMOND structured education programme[16], which included a module on either blood or urine self-monitoring. Follow-up data were collected at 6, 12 and 18 months post-education. Ethical approval was received from a Research Ethics Committee (07/H0304/129) and local research governance approval from participating health trusts.

Setting and participants

Sixty-five general practices (from inner city to rural settings) in England referred adults with Type 2 diabetes to the study within 12 weeks of diagnosis. They were excluded if they were under 18 years, using insulin, had severe and enduring mental health problems, were not primarily responsible for their own care, were unable or unwilling to participate in a group programme or were taking part in another research study. Participants were required to attend the DESMOND programme within six months of diagnosis and were not eligible if they had already started regular self-monitoring of blood glucose.

Randomisation

The study was cluster-randomised, with randomisation at practice level, after stratification for site and practice list size. The study was unblinded but practices agreed to participate prior to randomisation and were not informed of their study arm allocation. However, it is likely that they became aware over time as participants attended the practice for ongoing clinical support and repeat prescriptions for monitoring resources. Practice staff were instructed to refer patients without telling them which arm they had been allocated to and patients were not informed of their study arm allocation until they had given informed consent.

Study intervention

Participants attended the DESMOND 'Newly Diagnosed' programme[16]. This is delivered by two trained and accredited educators as a single 6-hour session or two 3-hour sessions one week apart, and usually includes a 20-minute session covering both urine and blood self-monitoring. For the study, the time spent discussing self-monitoring was extended to 100 minutes, and the course was delivered in two sessions, one week apart. The development, content, and piloting of the new self-monitoring modules are described in the protocol paper[17]. The approach to self-monitoring was non-directive, but promoted the practice of self-monitoring as a tool to support decision-making in regard to lifestyle changes and medication use. Participants were encouraged to discover when and how often to monitor, as well as how to interpret results and explore options for change. Although participants were

allocated to blood or urine self-monitoring, they were free to change their method of monitoring or to stop monitoring at any time. During the study, they obtained further monitoring supplies by requesting a prescription from their practice. Most participants were exempt from prescription charges and the small number liable to pay, were refunded any charges they incurred. Practices were also refunded the prescribing costs to prevent cost being a barrier to self-monitoring or to participation in the trial.

The primary outcome was mean glycated haemoglobin (HbA1c) at 18 months. The secondary outcomes included biomedical and psychosocial variables, measured at 6, 12 and 18 months. Biomedical measures included lipid profile, blood pressure, body weight and waist circumference. Psychosocial processes and outcomes were measured using questionnaires covering various aspects of diabetes and self-monitoring. Satisfaction with treatment was assessed using the Diabetes Treatment Satisfaction Questionnaire[18], which measures: 1) 'total treatment satisfaction' 2) 'perceived frequency of hyperglycaemia' and 3) 'perceived frequency of hypoglycaemia'.

Psychological well-being was measured using the 28-item Well-Being Questionnaire[18], from which two 12-item constructs were produced: 1) 'generic well-being' and 2) 'diabetes-specific well-being'. Perceptions of diabetes were measured using a diabetes-specific version of the Brief Illness Perceptions Questionnaire[19]. For all measures, a higher score indicates more of the construct being measured.

The trial was designed as a non-inferiority trial with the aim of demonstrating a mean equivalence in HbA1c at 18 months of within 5 mmol/mol ($\pm 0.5\%$).

Assuming, at 18 months, a conservative standard deviation of 16 mmol/mol (1.5%)[20], 80% power and 5% significance, 142 participants were required per arm, increasing to 163 per arm to allow for clustering, assuming an intra-cluster correlation of 0.05 and mean cluster size of four. Assuming 20% non-consent and 20% drop-out, numbers required were 254 referrals and 204 consenting per arm.

Baseline characteristics were summarised by group at each follow-up point as was the monitoring method that the participant reported using. For each outcome and follow-up, the mean (standard error) change from baseline at each follow-up was estimated by arm and compared using generalised estimating equations adjusted for baseline value and a term that accounted for the practice-level clustering. These equations assumed an exchangeable correlation matrix, robust standard errors and a normal distribution for the data, except for the reported monitoring method, which used a Binomial distribution. The primary analyses followed the intention-to-treat principle and data were analysed according to randomisation arm, regardless of whether participants continued to use that monitoring method or provided follow-up data. Missing data were replaced using multiple imputation, which accounted for the clustering as far as possible except where this meant that the model would not converge (waist circumference, systolic and diastolic blood pressure, HDL and LDL cholesterol and W-BQ28 'generic well-being', because the models that accounted for site did not converge).

Analyses were repeated in two key subsets: 1) only those with complete data available, i.e. with no imputation of missing data, and 2) only those who were using their randomised monitoring method at the follow-up time point of interest. The latter is analogous to a per protocol analysis in an individually randomised trial and, thus, is referred to as 'per protocol' from herein for ease of understanding. All p-values are two-sided and statistical significance was assessed at the 5% level. Analyses were conducted in Stata 12.1. Data are presented as estimate [95% confidence interval].

Results

The participant flow is shown in Figure 1. A total of 75 general practices were recruited and randomised; 37 to blood monitoring and 38 to urine monitoring. The blood monitoring practices referred 253 people, of whom 140(55%) consented to join the study. The urine monitoring practices referred 275 people, of whom 152(55%) joined the study (Fig 1). The main reasons for non-participation were no longer interested in taking part, booked but did not attend, unable to arrange a suitable date and unable to contact. The baseline characteristics of those who consented are shown in Table 1. There was no significant difference within randomisation groups in age, gender or baseline HbA1c in those who did and did not provide biomedical data at 18 months. Participants who did not complete the questionnaire at 18 months were younger than respondents in both arms (blood: $p<0.001$; urine: $p=0.05$) but did not differ in terms of HbA1c (blood: $p=0.45$; urine: $p=0.74$) or gender (blood: $p=0.12$; urine: $p=0.71$).

Results for the biomedical outcomes are shown in Table 2. There was a significant reduction in HbA1c from baseline in the blood monitoring group of 13(SE = 2) mmol/mol (1.2%(SE = 0.2%)) at 6 months, of 12(2) mmol/mol (1.1%(0.2%)) at 12 months, and of 12.0(2.2) mmol/mol (1.1%(0.2%)) at 18 months. Likewise, there was a significant reduction in the urine monitoring group of 15(2) mmol/mol (1.4%(0.2%)) at 6 months, of 14(2) mmol/mol (1.3%(0.2%)) at 12 months, and of 13(2) mmol/mol (1.2%(0.2%)) at 18 months. There were no significant differences between groups in terms of HbA1c change at each follow-up (Table 2).

Likewise, there were improvements from baseline in body mass index, waist circumference, weight, systolic and diastolic blood pressure, and total and LDL cholesterol in both monitoring groups at each follow-up (most of which were statistically significant, with no significant differences between groups at each follow-up (Table 2). Sensitivity and per protocol analyses showed no significant differences between the two groups for any of the biomedical outcomes (Supplementary Table 1).

In both groups, there were improvements from baseline in total treatment satisfaction, generic well-being, diabetes-specific well-being, and diabetes was perceived as less threatening; most of which were statistically significant (Table 3). There were no significant changes in perceived frequency of hyper- or hypoglycaemia. The only significant difference between the groups was that at 6 months, people randomised to urine monitoring perceived diabetes

as less threatening than those randomised to blood monitoring (difference = -2.8; 95% CI = -5.3, -0.3).

Sensitivity and per protocol analyses (Supplementary Table 2) show that many of the previously non-significant differences between groups strengthened and became statistically significant. When only complete data were analysed (i.e. missing data not imputed), the urine monitoring group were less satisfied with their treatment, had better generic and diabetes-specific well-being, and a less threatening view of diabetes, for at least one follow-up time point. In per protocol analyses, the urine monitoring group reported lower perceived frequency of hyperglycaemia and a less threatening view of diabetes at 6 months.

Participants randomised to blood monitoring were more likely to be using their randomised monitoring method than urine monitoring participants at 6 months (86% vs 74%, $p=0.04$), 12 months (85% vs 69%, $p=0.01$), and 18 months (79% vs 59%, $p<0.01$) (Fig 2). However, the proportion of participants who did not monitor at all was not significantly different between the groups (6 months: 12% vs 8%, $p=0.14$; 12 months: 12% vs 14%, $p=0.70$; 18 months: 17% vs 20%, $p=0.58$). Rather, those initially randomised to urine monitoring tended to switch to blood monitoring whilst those initially randomised to blood monitoring almost never switched method (6 months: 12% vs 1%, $p=0.01$; 12 months: 11% vs 0%, $p<0.001$; 18 months: 18% vs 1%, $p<0.01$). In both groups, participants who were monitoring were most likely to be doing so 1 to 3 times per week (data not shown). Half of the participants were prescribed metformin

during the study. This usually happened at diagnosis (48% by 6 months) with small increases in prescription rates occurring over time (50% and 54% at 12 and 18 months). There were no differences between the two arms.

Discussion

Both groups showed significant improvements in HbA1c and other biomedical and psychosocial outcomes during the study, but there no significant differences in changes between the groups, indicating that blood monitoring provided no additional benefit when compared with urine monitoring.

Our study had a robust, multi-site cluster design, to prevent contamination between groups, and a clinically relevant follow-up period of 18 months. It was conducted in a primary care setting, with broad inclusion criteria; it involved attending a structured education intervention that is delivered widely in the UK, and participants were recruited using a standard referral pathway. The pragmatic study design therefore embeds it in the real world and provides good external validity. Validated generic and diabetes-specific questionnaires were used in the evaluation. The two groups were well matched, and the fact that both received the same amount of education enabled us to control for effects of education. Although eligibility for referral did not include a minimum HbA1c level, the mean value at baseline of 65 mmol/mol (8.1%) was high enough to show improvement. This has been a weakness of other studies where a low baseline HbA1c may have caused a 'floor effect' [12,21,22].

The study limitations include a lower consent rate than anticipated (although rates were identical in each arm), which resulted in not recruiting to target. However, sample size calculations were based on a predicted standard deviation in HbA1c at the end of the study of (16mmol/mol(1.5%)), while the actual standard deviation (11mmol/mol(1.0%)) was lower than this. Substituting the observed SD into the sample size calculation and keeping other assumptions the same, the required sample size would be 73 participants per arm, indicating that the study was adequately powered to meet its primary objective. The low consent rate was due to logistical problems that commonly occur in standard clinical pathways (e.g.difficulty contacting patients, cancellation and non-attendance). The level of data return dropped from 91% at 6 months to 71% at 18 months. However there were no significant differences at baseline in age, gender or HbA1c between those who did and did not provide follow-up data, and sensitivity analysis suggests that level of data return did not have a large impact on results. The information and support that participants received for self-monitoring was almost exclusively from the DESMOND course. Although healthcare professionals in participating practices received a training visit before the trial[17], and were asked to provide impartial support and advice on self-monitoring during the study, their input was unlikely to have been large. Furthermore some participants in the qualitative sub-study (Eborall, Submitted to Diabetic Medicine) reported a lack of support from healthcare professionals with interpreting results and in some cases disapproval of the method. Thus, the full potential of blood monitoring to effect changes in self-management may have been limited.

Systematic reviews and meta-analyses[3-7], as well as recently published studies not included in the reviews[23-26], have generally reported little benefit in biomedical outcomes of self-monitoring of blood glucose in people with non-insulin treated Type 2 diabetes with one exception. When the approach to monitoring is “structured”, with participants following clearly defined monitoring schedules and receiving regular feedback and advice from trained healthcare professionals, then clinically relevant improvements in glycaemic control have been observed[23-26]. However, studies of “structured” self-monitoring are efficacy trials and cannot be compared closely with our trial, which was pragmatic, conducted in primary care and involved a single session of group education with relatively little input from healthcare professionals at practice level. The DiGEM study[22] also conducted in primary care in the UK reported no difference in HbA1c at 12 months in patients with established Type 2 diabetes randomised to a control group (no monitoring) or one of two blood monitoring groups in which one received education and feedback from trained practice nurses.

Only two recent trials have evaluated self-monitoring of blood glucose in people with newly diagnosed Type 2 diabetes[11,12] and these showed conflicting results. In the ESMON study[11], there were large but similar improvements in HbA1c over 12 months in both groups (21mmol/mol(1.9%)) in those who used blood monitoring and (19mol/mol)1.7%)) in those who did not monitor), while in the St Carlos Study[12], the group using self-monitoring showed greater “remission” and “regression” compared with the group that did

not monitor. In both studies, referral took place in hospital clinics and the interventions included substantial amounts of one-to-one education with healthcare professionals as well as quarterly HbA1c tests, which were used to inform changes in medication. Fundamental differences in design therefore make it difficult to compare the results of these trials with our own.

In our study, the proportion switching methods or stopping monitoring altogether was greater in the urine monitoring group who tended to report less satisfaction with their treatment. The qualitative sub-study (Eborall, Submitted to Diabetic Medicine) has helped explain this: interviewees reported blood monitoring as accurate, convenient and useful in a practical sense for managing their diabetes, while many initially positive views of urine monitoring lessened over time as interviewees came to find it inaccurate. This is supported by previous qualitative work which reported a perception of urine monitoring as inconvenient and unhygienic[27].

With regard to psychosocial outcomes, those randomised to urine monitoring in our study had a tendency toward better generic and diabetes-specific well-being at follow-up, consistent with trials reporting that emotional well-being may be adversely affected by blood monitoring, including increased anxiety[11,28] and depressive symptoms[11,29]. In addition, those using urine monitoring in the present study reported a less threatening view of diabetes (at 6 months). Our qualitative sub-study suggested that urine monitoring provided insufficient visibility of diabetes to interviewees, leading some to question their diagnosis (Eborall, Submitted to Diabetic Medicine). In contrast

blood monitoring provided a more visible reminder – both of having diabetes and of the effects of activities on blood glucose – which may have raised the level of threat perceived, echoing previous research where blood monitoring led to anxiety and self-blame in participants whose glucose readings were high[30].

We conclude that in the context of the present study, which reflects current practice in the UK, urine monitoring, as part of structured self-management education, is as effective as blood monitoring over the first 18 months after diagnosis. Many participants found urine monitoring useful and acceptable and if this method of self-monitoring was made available as the method of choice at diagnosis then it might lead to substantial cost savings without impairing outcomes. Nevertheless, the significant number who chose to switch to blood monitoring suggests that many found this more useful. These individuals should be permitted to do, but would need to be provided with ongoing advice and support by their healthcare team.

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Conflicts of interest

MJD has acted as consultant, advisory board member and speaker for Novartis, Novo Nordisk, Sanofi-Aventis, Lilly, Merck Sharp & Dohme, Boehringer Ingelheim and Roche and received grants in support of investigator and investigator initiated trials from Novartis, Novo Nordisk, Sanofi-Aventis, Lilly, Pfizer, Merck Sharp & Dohme and GlaxoSmithKline. KK has acted as consultant, advisory board member for Novo Nordisk, Eli Lilly, Merck Sharp & Dohme, Bristol Myers Squibb, Roche and received payment for lectures from Novo Nordisk, Eli Lilly, Sanofi-Aventis, Novartis, Merck Sharp & Dohme, Janssen, Astra Zeneca, Boehringer Ingelheim Ltd. JS has received consultancy fees from Roche Diagnostics Australia, and grants and consultancy fees from Sanofi Diabetes. SH reports personal fees from Lifescan. Other authors have nothing to declare.

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Author Contributions: SH, MJD, KK, HMD, MEC and JS were involved in study conception and design; HMD and MH managed the study; DB, MC

provided statistical input and analysis; HMD, SH, JS, HE and DB were involved in drafting the paper. All authors contributed to editing and approved the final text.

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Table 1. Baseline characteristics of study participants by monitoring group.

Variable	Blood monitoring (N = 140)	Urine monitoring (N = 152)
Demographic factors		
N (%) Women	69 (49.3)	65 (42.8)
N (%) White European	124 (93.9)	121 (87.1)
Age, years	57.1 (11.3)	59.4 (11.6)
Biomedical measures		
HbA1c, mmol/mol	65 (22)	66 (23)
HbA1c, %	8.1 (4.2)	8.2 (4.3)
Total cholesterol, mmol/l	5.3 (1.2)	5.3 (1.4)
HDL cholesterol, mmol/l *	1.2 (0.4)	1.2 (0.3)
LDL cholesterol, mmol/l*	3.0 (1.1)	3.1 (1.1)
Systolic blood pressure, mm/Hg	135.5 (15.1)	136.2 (15.6)
Diastolic blood pressure, mm/Hg	81.5 (10.1)	81.4 (12.1)
Weight, kg	94.4 (20.2)	91.8 (18.5)
Waist circumference, cm*	107.3 (16.1)	106.1 (15.6)
BMI, kg/m ²	34.2 (10.8)	32.8 (7.9)
Psychosocial measures		
<i>DTSQs</i>		
Total treatment satisfaction * (score range: 0-36)	25.8 (8.0)	24.5 (8.4)
Perceived frequency of hyperglycaemia* (score range: 0-6)	1.8 (1.9)	1.6 (1.8)
Perceived frequency of hypoglycaemia* (score range: 0-6)	0.9 (1.4)	0.9 (1.3)
<i>W-BQ28</i>		
12-item generic well-being (score range: 0-36)	21.7 (6.7)	23.2 (6.6)
Diabetes-specific well-being (score range: 0-36)	23.9 (7.2)	24.8 (7.1)
<i>BIPQ</i>		
Threatening view of diabetes * (score range: 0 - 80)	35.1 (12.8)	33.8 (12.1)

Data are mean (standard deviation).

Abbreviations: DTSQ, Diabetes Treatment Satisfaction Questionnaire; W-BQ28, Well-Being Questionnaire; BIPQ, Brief Illness Perceptions Questionnaire.

*More than 20% of the data for these variables were missing. For all variables, missing values were imputed prior to data analysis (see Methods).

Table 2. Mean changes from baseline for biomedical outcomes by monitoring group (n=292)

Variables	Mean (SE) change from baseline		Difference (95% CI) between monitoring groups ^a
	Blood monitoring	Urine monitoring	
HbA1c, mmol/mol			
6 months	13 (2) ***	15 (2) ***	0 (-3, 2)
12 months	12 (2) ***	15 (2) ***	0 (-3, 2)
18 months ^b	12 (2) ***	13 (2) ***	-1 (-3, 2)
HbA1c, %			
6 months	-1.20 (0.16)***	-1.40 (0.19)***	-0.01 (-0.23, 0.22)
12 months	-1.08 (0.18)***	-1.33 (0.20)***	-0.02 (-0.27, 0.24)
18 months ^b	-1.13 (0.21)***	-1.20 (0.20)***	-0.05 (-0.28, 0.18)
BMI, kg/m ²			
6 months	-1.28 (0.21)***	-1.03 (0.29)***	0.17 (-0.49, 0.82)
12 months	-1.04 (0.34)**	-0.86 (0.23)***	0.38 (-0.34, 1.10)
18 months	-0.80 (0.43)	-1.06 (0.42)*	-0.64 (-1.59, 0.31)
Waist circumference, cm			
6 months	-1.99 (1.15)	-2.87 (0.96)**	-0.54 (-2.42, 1.33)
12 months	-2.97 (2.88)	-1.80 (1.73)	-0.55 (-3.96, 2.86)
18 months	-3.07 (3.42)	-2.98 (1.52)	0.01 (-2.58, 2.61)
Weight, kg			
6 months	-3.59 (0.70)***	-2.97 (0.73)***	0.02 (-1.87, 1.92)
12 months	-2.86 (0.95)**	-2.80 (0.65)***	-0.17 (-2.29, 1.94)
18 months	-1.45 (1.28)	-3.62 (1.25)**	0.12 (-3.09, 3.33)
Systolic BP, mmHg			
6 months	-2.49 (1.67)	-4.11 (1.68)*	-0.96 (-4.41, 2.49)
12 months	-4.39 (2.22)	-4.20 (2.06)*	1.05 (-2.13, 4.24)
18 months	-1.60 (2.30)	-3.98 (1.83)*	-0.41 (-3.36, 2.55)
Diastolic BP, mmHg			
6 months	-3.32 (1.10)**	-3.54 (0.93)***	-0.75 (-2.55, 1.05)
12 months	-4.88 (1.22)***	-3.37 (1.18)**	0.53 (-1.52, 2.59)
18 months	-2.56 (1.52)	-3.63 (2.63)	-0.63 (-3.07, 1.81)
Total cholesterol, mmol/l			
6 months	-0.77 (0.13)***	-0.98 (0.13)***	-0.20 (-0.46, 0.06)
12 months	-1.04 (0.15)***	-0.99 (0.14)***	-0.12 (-0.35, 0.12)
18 months	-1.02 (0.14)***	-0.97 (0.15)***	-0.07 (-0.27, 0.12)
HDL cholesterol, mmol/l			
6 months	-0.02 (0.05)	0.03 (0.03)	0.02 (-0.04, 0.08)
12 months	0.07 (0.03)*	0.14 (0.10)	0.03 (-0.07, 0.14)
18 months	0.02 (0.03)	0.01 (0.03)	0.00 (-0.05, 0.06)
LDL cholesterol, mmol/l			
6 months	-0.57 (0.12)***	-0.69 (0.15)***	0.03 (-0.28, 0.22)
12 months	-0.90 (0.18)***	-0.83 (0.16)***	0.01 (-0.19, 0.21)
18 months	-0.67 (0.19)**	-0.57 (0.17)**	-0.01 (-0.17, 0.15)

Abbreviations: BP, Blood Pressure; BMI Body mass index; CI, Confidence Interval; SE, Standard Error. * P < 0.05, ** P < 0.01, *** P < 0.001

^aAdjusted for baseline value and cluster effect. Analyses follow the intention-to-treat principle and so missing data were imputed.

^bHbA1c at 18 months is the primary outcome defined in the study protocol. All other outcomes are secondary outcomes.

Table 3. Mean changes from baseline for psychosocial outcomes by monitoring group (N=292).

Variables	Mean (SE)		Difference (95% CI) between monitoring groups ^a
	Blood monitoring	Urine monitoring	
DTSQs Total treatment satisfaction			
6 months	4.18 (0.96)***	3.12 (0.96)**	-1.23 (-2.86, 0.41)
12 months	3.19 (0.87)***	1.41 (0.77)	-1.24 (-2.69, 0.21)
18 months	4.58 (0.98)***	3.12 (0.89)***	-1.09 (-3.35, 1.18)
DTSQs Perceived frequency of hyperglycaemia			
6 months	0.12 (0.23)	-1.61 (1.41)	-1.15 (-3.56, 1.27)
12 months	0.21 (0.27)	-1.77 (1.44)	-1.30 (-4.13, 1.54)
18 months	-0.38 (0.25)	-0.24 (0.20)	-0.08 (-0.47, 0.30)
DTSQs Perceived frequency of hypoglycaemia			
6 months	0.18 (0.16)	-3.06 (2.11)	-1.33 (-4.60, 1.95)
12 months	-0.03 (0.17)	-1.43 (1.53)	-0.50 (-2.95, 1.95)
18 months	0.11 (0.17)	-1.63 (1.58)	-0.45 (-2.76, 1.87)
W-BQ28 Generic well-being			
6 months	1.13 (0.44)*	1.62 (0.58)**	0.49 (-1.09, 2.07)
12 months	0.30 (0.47)	0.76 (0.70)	0.68 (-0.58, 1.95)
18 months	0.64 (0.54)	1.86 (0.64)**	0.78 (-0.68, 2.25)
W-BQ28 Diabetes-specific well-being			
6 months	2.32 (0.55)***	3.48 (0.61)***	1.04 (-0.44, 2.53)
12 months	2.23 (0.61)***	2.43 (0.59)***	0.34 (-0.82, 1.50)
18 months	3.14 (0.65)***	3.39 (0.68)***	0.66 (-0.64, 1.97)
B-IPQ Threatening view of diabetes			
6 months	-1.71 (1.16)	-6.25 (1.29)***	-2.78 (-5.26, -0.31)*
12 months	-2.90 (1.31)*	-4.67 (1.23)***	-2.04 (-5.09, 1.01)
18 months	-3.35 (1.32)*	-4.84 (1.33)***	-0.00 (-2.54, 2.53)

Abbreviations: SE, Standard error; CI, Confidence Interval; DTSQ, Diabetes Treatment Satisfaction Questionnaire; W-BQ28, Well-Being Questionnaire; BIPQ, Brief Illness Perceptions Questionnaire

* P < 0.05, ** P < 0.01, *** P < 0.001

^a Adjusted for baseline value and cluster effect. Analyses follow the intention-to-treat principle and so missing data were imputed.

Figure 1. CONSORT diagram showing the flow of patients through the trial.

Figure 2. Self-reported monitoring method at each time point among participants who provided questionnaire data.

Supplementary Table 1. Sensitivity and per protocol analyses showing changes from baseline for biomedical outcomes.

Variables	Complete data		Per protocol	
	N	Difference (95% CI) †	N	Difference (95% CI) †
HbA1c, mmol/mol				
6 months	235	-1 (-3, 1)	164	0 (-2, 3)
12 months	191	-1 (-3, 2)	143	1 (-4, 2)
18 months	188	-1 (-4, 1)	138	0 (-3, 2)
HbA1c, %				
6 months	235	-0.1 (-0.3, 0.1)	164	0 (-0.2, 0.3)
12 months	191	-0.1 (-0.3, 0.2)	143	-0.1 (-0.4, 0.2)
18 months	188	-0.1 (-0.4, 0.1)	138	0 (-0.3, 0.3)
BMI, kg/m²				
6 months	195	0.2 (-0.6, 1.0)	164	-0.4 (-1.2, 0.5)
12 months	156	0.2 (-0.7, 1.0)	143	0.1 (-0.9, 1.1)
18 months	141	-0.2 (-1.2, 0.8)	138	-0.4 (-1.6, 0.9)
Waist circumference, cm				
6 months	74	-0.5 (-2.9, 1.9)	164	-1.44 (-5.2, 2.3)
12 months	57	2.3 (-3.0, 7.6)	143	-2.9 (-6.8, 0.9)
18 months	35	-0.6 (-9.5, 8.3)	138	-0.9 (-4.2, 2.4)
Weight, kg				
6 months	211	0.1 (-1.8, 2.1)	164	-0.9 (-3.2, 1.4)
12 months	173	0.1 (-2.2, 2.3)	143	0.4 (-1.8, 2.7)
18 months	154	-2.1 (-5.3, 1.1)	138	-0.3 (-3.9, 3.4)
Systolic BP, mmHg				
6 months	195	-1.7 (-5.5, 2.0)	164	-0.8 (-5.7, 4.1)
12 months	125	0.6 (-3.0, 4.2)	143	1.7 (-3.1, 6.5)
18 months	96	-1.8 (-6.0, 2.5)	138	-0.4 (-4.6, 3.8)
Diastolic BP, mmHg				
6 months	191	-1.2 (-3.3, 0.9)	164	-0.8 (-3.5, 1.9)
12 months	124	0.1 (-2.5, 2.7)	143	0.2 (-3.3, 3.6)
18 months	94	-1.8 (-6.2, 2.6)	138	2.33 (-1.2, 5.9)
Total cholesterol, mmol/l				
6 months	202	-0.2 (-0.5, 0.1)	164	-0.2 (-0.5, 0.1)
12 months	161	0 (-0.3, 0.3)	143	-0.1 (-0.4, 0.2)
18 months	145	-0.1 (-0.3, 0.2)	138	-0.1 (-0.3, 0.2)
HDL cholesterol, mmol/l				
6 months	145	0 (-0.1, 0.1)	164	0 (-0.1, 0.1)
12 months	100	0.1 (-0.1, 0.3)	143	0 (-0.1, 0.1)
18 months	76	0 (-0.1, 0.1)	138	-0.1 (-0.2, 0.1)
LDL cholesterol, mmol/l				
6 months	132	-0.1 (-0.4, 0.2)	164	-0.1 (-0.4, 0.2)
12 months	93	-0.1 (-0.4, 0.2)	143	-0.1 (-0.4, 0.3)
18 months	68	0 (-0.4, 0.5)	138	-0.1 (-0.4, 0.2)

Abbreviations: CI, Confidence Interval; BP, Blood Pressure; BMI, Body mass index

* P < 0.05, ** P < 0.01, *** P < 0.001

† Adjusted for baseline value and cluster effect.

Supplementary Table 2. Sensitivity and per protocol analyses showing changes from baseline for psychosocial outcomes.

Variables	Complete data		Per protocol	
	N	Difference (95% CI) †	N	Difference (95% CI) †
DTSQs Total treatment satisfaction				
6 months	136	-1.4 (-3.3, 0.5)	164	-0.6 (-2.6, 1.4)
12 months	133	-2.0 (-3.6, -0.4)*	143	-1.8 (-3.6, 0.9)
18 months	137	-2.0 (-3.9, 0)*	138	-1.3 (-3.8, 1.1)
DTSQs Perceived frequency of hyperglycaemia				
6 months	148	-1.9 (-4.5, 0.8)	164	-0.7 (-1.1, -0.3)**
12 months	140	-2.2 (-4.8, 0.5)	143	-0.7 (-2.8, 1.5)
18 months	141	-0.2 (-0.6, 0.3)	138	-0.4 (-1.0, 0.2)
DTSQs Perceived frequency of hypoglycaemia				
6 months	143	-3.3 (-7.2, 0.7)	164	-1.4 (-5.9, 3.1)
12 months	135	-1.4 (-4.4, 1.0)	143	-0.3 (-2.8, 2.1)
18 months	136	-1.7 (-4.8, 1.3)	138	-2.1 (-6.0, 1.8)
W-BQ28 12-item General well-being				
6 months	170	0.6 (-0.5, 1.8)	164	0.7 (-0.7, 2.0)
12 months	158	1.1 (-0.8, 2.9)	143	1.3 (-0.6, 3.3)
18 months	165	1.5 (0.2, 2.8)*	138	1.6 (-0.5, 3.8)
W-BQ28 Diabetes-specific well-being				
6 months	176	2.0 (0.3, 3.7)*	164	1.5 (-0.3, 3.2)
12 months	154	0.9 (0, 2.6)	143	0.5 (-1.4, 2.5)
18 months	167	0.9 (-0.7, 2.5)	138	1.7 (-0.0, 3.5)
B-IPQ Threatening view of diabetes				
6 months	150	-5.1 (-8.1 -2.12)**	164	-4.8 (-8.3, -1.4)**
12 months	135	-2.7 (-6.1, 0.6)	143	-3.5 (-7.6, 0.6)
18 months	148	-1.6 (-4.6, 1.4)	138	-2.3 (-6.2, 1.7)

Abbreviations: CI, Confidence Interval; DTSQ, Diabetes Treatment Satisfaction Questionnaire; W-BQ28, Well-Being Questionnaire; BIPQ, Brief Illness Perceptions Questionnaire

* P < 0.05, ** P < 0.01, *** P < 0.001

† Adjusted for baseline value and cluster effect.