The Use of Continuous Glucose Monitoring for Sport in Type 1 Diabetes

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Abstract

The benefits of exercise for patients with Type 1 Diabetes (T1D) are difficult to balance with associated glycaemic excursions. The aim of this study was to show that Continuous Glucose Monitoring (CGM) could reduce glycaemic excursions in patients with T1D already using insulin pumps, exercising at moderate to high intensity. Questionnaires were used to identify T1D patients using insulin pumps and naïve to CGM use, who reported regular exercise. 6 were enrolled and trained on Enlite sensor use with Medtronic Minimed Paradigm® Veo™ system, and given activity trackers and written advice on adjustment of insulin or carbohydrate intake for exercise. Resting heart rate (HR) and age were used to determine HR surrogates of moderate and high intensity exercise. They were to exercise as usual for 3 weeks (run-in week, week 1 and week 2), using the activity trackers and heart rate monitors. PAID, HFSII, DTQ and Gold scores were completed prior to run-in and at the end. The downloaded sensor glucose data was used to compare the change in time in range (glucose 3.9–10.0 mmol/l) from week 1 to week 2 For the duration of exercise this time range glucose range increased from 72 ± 20 to 88 ± 16%, p=0.05. The time in hypoglycaemia range (glucose <3.9 mmol/l) went from 3.9 ± 7.9 to 2.4 ± 4.8%, p=0.39. The time in hyperglycaemia range (>10 mmol/l) reduced from 24 ± 19 to 10 ± 17%, p=0.04. These results demonstrate the benefit of CGM use for patients with T1DM doing moderate to high intensity exercise.

Introduction

Exercise is recommended to patients with Type 1 Diabetes to improve their cardiovascular health and reduce their risk factors for cardiovascular disease [1]. However exercise, especially moderate to high intensity exercise, can lead to excursions in glucose levels that are difficult to manage [2]. Education about appropriate insulin dose adjustments for different types of exercise can be very helpful, but is not always enough to eliminate this problem [3]. The use of Insulin pump therapy instead of multiple daily injections can also help [4] but even patients using this form of insulin delivery, where the insulin basal rate can be adjusted readily, often continue to struggle with control during or immediately after exercise also occur [9]. Hyperglycaemia is more likely to occur after aerobic exercise sessions is a typical problem [7,8], but hypoglycaemia and hyperglycaemia during or immediately after exercise also occur [9]. Hyperglycaemia is more likely to occur after high intensity or anaerobic exercise [10]. Patients sometimes target hypoglycaemia before exercise as a mechanism of avoiding hypoglycaemia during it. A useful tactic to avoid hypoglycaemia during exercise is to intersperse a 10 second sprint into a lower intensity aerobic exercise session [11]. Studies in controlled settings have demonstrated the benefit of using real-time Continuous Glucose Monitoring (CGM) to inform insulin and carbohydrate adjustments to avoid wide glycaemic excursions [12,13]. The aim of this study was to examine the benefit of CGM for patients involved in regular moderate to high intensity exercise, in the real-life setting.

Methods

Approval for the study was obtained from Galway University Hospital Clinical Research Ethics committee. Questionnaires were sent to all type 1 Diabetes patients using insulin pumps attending the Diabetes clinic at Galway University Hospital. Those naïve to real-time CGM use, who reported regular (at least twice per week) moderate to high intensity exercise were invited to participate. 6 were enrolled and trained on Enlite sensor use with Medtronic Minimed Paradigm® Veo™ system. All were given written general advice on adjustment of insulin or carbohydrate intake, for different exercise intensities, duration and proximity to mealtime (Figure 1). This is adapted from Exercise management in type 1 diabetes: a consensus statement [14].
They were also given Polar ProTrainer 5™ watches and shown how to use them with the accompanying heart rate monitor chest strap, to monitor their heart rate during exercise sessions. We measured their resting heart rate, and together with age this was used to calculate the age predicted maximum heart rate (220-age=HRmax). Using the Karvonen method we determined heart rate reserve (HRR=HRmax-HRrest). HR ranges 40% to 70% and 70% to 80% of HRR added to HRrest were used as surrogates of moderate and high intensity exercise respectively. Weight, BMI and BP were recorded at baseline, and a blood sample was sent to test Hba1c (IFCC assay). They were instructed to exercise as usual for 3 weeks, turning the Polar watch on for the duration of exercise. The Moves app was installed on their own smartphones that they were asked to carry always to monitor their level of activity at times when they were not exercising. At the end the run-in (week-1) subjects were contacted to troubleshoot any calibration or sensor change problems. If they consistently wore the sensor, exercised at least twice per week and used the Polar™ watch for exercise during the run-in week they were included in the study. 2 subjects were not included. In one case this was because regular exercise was not carried out due to an injury, in the other case it was because there was difficulty using Polar watch and heart rate monitor for exercise sessions which involved rugby training.

Problem areas in Diabetes (PAID) [15], Hypoglycaemia fear survey II (HFSII) [16], Diabetes Technology Questionnaire (DTQ) [17] were completed prior to run-in and at the end of the study and the Gold score [18] was obtained from each individual before the study to assess their level of hypoglycaemia unawareness. (This is a simple score from 1-7 in response to the question: Do you know when your hypos are commencing? Where 1 is where you are always aware and 7 means you are never aware). These are all validated questionnaires designed to quantify quality of life and hypoglycaemia unawareness and changes in these parameters over time.

The downloaded sensor glucose data on Carelink™ Personal (Medtronic software for patient and health professional review of insulin and glucose data) was analysed in SPSS. Thresholds for glucose levels were set as follows: target range 3.9 mmol/l to 10 mmol/l, hypoglycaemia range <3.9 mmol/l, hyperglycaemia range >10 mmol/l. All available sensor glucose values were included in the analysis (one value is provided every 5 minutes while the sensors are worn). The periods of time the patients spent exercising were determined from the heart rate monitor where glucose data associated with a heart rate...
at least $0.4 \times (HRR - HR_{\text{rest}})$ was included. Student’s paired t-test was used to compare time in the range, in week 1 to week 2.

**Additional recommendations**

If first-time exercise there is a prolonged hypoglycaemia risk so the basal rate should be reduced for the entire night using temporary basal rate setting, if on MDI the long acting dose should be reduced that day/night. Hypoglycaemia risk is also higher if exercise is carried out on sequential days, or there was a hypoglycaemic event on the day preceding exercise. Alcohol also increases the risk of hypoglycaemia. If hyperglycaemia is encountered post-exercise (especially likely if mod/high intensity exercise at the anaerobic/lactate threshold) a cool-down over 20 minutes to 30 minutes will reduce the need to give a correction bolus. A 10-second sprint done before and/or during low/moderate intensity exercise will elevate glucose levels and reduce the risk of hypoglycaemia during or after exercise.

**Results**

Figure 2 the sensor glucose values were binned into time in target, time in hypoglycaemia range and time in hyperglycaemia range and are shown as percentage in each range. Figure 2a all available glucose values over the 2 weeks for the study are divided into the 3 different ranges and week 1 is compared to week 2. Figure 2b the glucose values that correspond to the time of exercise (determined from the Polar watch HR data (all time that $HR + HRR > 40\% \, HR_{\text{max}}$) was divided into the 3 target ranges and compared between week 1 and week 2. Figure 2c shows the glucose values from 1 hour before to 4 hours after exercise. 3 of the subjects wore sensors for all 21 days of the study, 1 wore it for 19 days. The percentage of missing data points did not differ significantly from week to week and duplicates were removed. There was an increase in the time in the target glucose range during exercise, in week 2 compared to week 1 72.4 ± 20% to 88.1 ± 15.6% ($p=0.05$), and a reduction in the time in the hyperglycaemia range (24 ± 19% to 10 ± 17% $p=0.04$ (Figure 2b). There was no significant reduction in hypoglycaemia, however the improvement in the time in target is not all attributable to reduction in the time in the hyperglycaemia range-the mean time in the hypoglycaemia during exercise reduced from 3.9 ± 7.9% to 2.4 ± 4.8%, $p=0.39$. When the sensor glucose data for the entire 2 week period was evaluated, there was no significant difference from week 1 to week 2 (Figure 2a), or for the time from 1 hour before to 4 hours after exercise (Figure 2c).

The Gold score ranged from 1-4 indicating no hypoglycaemia unawareness in one individual, and a mild to moderate degree in the other subjects. The other quality of life measures showed low levels of anxiety (HFS II Worry scale scores were 13 ± 16 out of a possible 0-72), and behaviour due to fear of hypoglycaemia (14 ± 7 out of a possible 0-48). The PAID scores were also moderate (16 ± 14 out of a possible 0-80). Nonetheless all of the QOL scores showed a non-significant trend toward improving following use of the CGM for the duration of the study.

**Discussion**

This small real-life study demonstrates the potential benefit of using CGM for exercise. We showed that there was a significant improvement in the time that interstitial glucose was in the target range.
range (3.9 mmol/l to 10 mmol/l) during exercise. These patients were involved in a variety of types of exercise, cycling, running, soccer and weight lifting and all had improvements in their glycaemic control during exercise between week 1 and week 2 of the study. Although there was no significant change in the time in the hypoglycaemia range from week 1 to week 2, there was a trend in this direction, and the time spent in the hypoglycaemia range was small. This difference didn’t reach significance probably in part due to the small number of subjects. The same reason may explain the lack of difference in the time in target range overall from week 1 to week 2 (including time exercising and not), where time in the hypoglycaemia reduced from 5.6 ± 3.1% to 3.4 ± 1.2% p=0.15, and hyperglycaemia time reduced from 29 ± 16% to 25 ± 15% p=0.11. Similar results were found for the time from 1 hour before and exercise session started to 4 hours afterward. This is a period that carries a high risk for wide glycaemic excursions; we expect a larger study would show significant reductions in time in the hypoglycaemia and hyperglycaemia ranges during this period. Our study showed a high proportion of time in hypoglycaemia during this time (8.9 ± 14.9% in week 1, 4.1 ± 3.8% in week 2).

The subjects used the CGM system for a run-in week and there were no overall significant improvements demonstrated between that week and subsequent weeks, suggesting that these patients needed some time to get used to the device and how to adjust their insulin according to the CGM glucose data available. The only input from the Diabetes research team was at the beginning of the study – when subjects were given basic instructions on insulin adjustment for exercise (Table 1), and shown how to use the study devices. There was a further contact after the run-in week, in person or by phone, to trouble-shoot any problems, but we did not review their data or provide individualised advice until the end of the study. Each subject had access to Carelink™ Personal and reviewed their data both in real-time and retrospectively to help to inform insulin dose adjustment. All of the patients were already insulin pump users, so the benefits they gained demonstrate the role of CGM in addition to adjust. All of the patients were already insulin pump users, so to be gained in terms of quality of life for patients who access CGM.

Table 2: Quality of Life Questionnaire Scores.

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Before Study Score</th>
<th>At end of study Score</th>
<th>Change in Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAID</td>
<td>16 ± 14</td>
<td>15 ± 11</td>
<td>-1.5 ± 6</td>
</tr>
<tr>
<td>HFS II Behaviour</td>
<td>14 ± 7</td>
<td>9 ± 2</td>
<td>-5.5 ± 8</td>
</tr>
<tr>
<td>HFS II Worry</td>
<td>13 ± 16</td>
<td>9 ± 9</td>
<td>-3.8 ± 12</td>
</tr>
</tbody>
</table>

To date cost-effectiveness analyses have not shown clear indications for the use of these devices [22]. The cost involved is not just that of the sensor enabled pump and sensors, but also the cost of the Diabetes educator hours involved in training patients on how to use these devices effectively. Here we have shown that a variety of insulin pump users can achieve benefits from the additional use of CGM with minimal input form the Diabetes team. All of these patients had previously attended a structured education course so had good baseline knowledge of how to adjust their insulin doses themselves. There also may be an element of selection bias and the individuals who agreed to participate may represent a cohort with a high level of motivation. However we feel this study demonstrates that a short trial of CGM use can quickly determine whether patients already using insulin pump therapy, are likely to be compliant with CGM use. Those patients participating in regular moderate to high intensity exercise are a cohort who can quickly benefit from the addition of CGM to improve their glucose time in the target range, and also improve their quality of life.

Type 1 Diabetes has a major impact on an individual’s lifestyle, including their ability to partake in exercise safely and enjoyably. Progress in technology for the treatment of Diabetes makes this more attainable. CGM whether as an integrated sensor augmented pump system or stand-alone device is available for selected patients, but many more stand to benefit from it especially those involved in regular moderate to high intensity exercise. New developments hold even more promise to improve the lives of these individuals. One study in the real-life setting to investigate the use of CGM along with an accelerometer and algorithm that incorporated the exercise intensity, showed reduction in hypoglycaemia [23]. The future incorporation of heart rate and other data into a closed loop device should further facilitate avoidance of glycaemic excursions around exercise. In the meantime, as we have shown in this small pilot study, sensor enabled insulin pumps have the potential to allow these patients to exercise while reducing their glycaemic excursions and anxiety about hypoglycaemia.

Compliance with Ethical Standards

Conflict of interest: none. All procedures performed in studies involving human participants were in accordance with the ethical
standards of GUH and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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References