A Novel Way to Represent Weekly Blood Sugar Data to Increase User Understanding and Control

P.J. Kyberd, Alix Chadwell, Matthew Lee and Farooq Othman Farooq Al Safi

Peter J. Kyberd, PhD
Department of Ortho and MSK Science, University College London, Brockley Hill, Stanmore, HA7 4LP, Middlesex, United Kingdom. p.kyberd@ucl.ac.uk

Alix Chadwell, PhD
School of Healthcare Enterprise and Innovation, University of Southampton, SO16 7NS . Centre for Human Movement and Rehabilitation, University of Salford, and Intelligent Sensing Research Group, Newcastle University. UK. A.Chadwell@soton.ac.uk

Matthew Lee, BEng
School of Energy and Electronic Engineering, Portland Building, Portland Street, Portsmouth, PO1 3AH, UK. up2039683@myport.ac.uk

Farooq Othman Farooq Al Safi, BEng
School of Energy and Electronic Engineering, Portland Building, Portland Street, Portsmouth, PO1 3AH, UK. up2048407@myport.ac.uk

ABSTRACT

Background: *Tight control of blood glucose is associated with good health. This is easier to achieve with continuous glucose monitoring. However, patients need to be able to interpret the data without reference to experts. Simplifying the visual display, can simplify decisions. Correct display of data can lead to improved control and health.*

Methods: *A novel method to display data: Mapping time series data onto a spiral - one day is a single turn, a week is seven. The colour of the line is related to the blood sugar level.*

Results: *Plots which are simpler and easier to interpret.*

KEYWORDS (TBD)

Diabetes Mellitus, Blood Glucose Self-Monitoring, Glycated Haemoglobin A

INTRODUCTION

Good blood glucose control is the result of patient education, motivation and information [1]. Quality information in an easily interpretable form is essential to ensure the patient can make appropriate decisions with minimal intervention from professionals [1]. Continuous Glucose Monitors (CGM) allow blood sugar to be measured more often, which results in better control [2]. With the amount of information, (a week's data is more than 700 datapoints), it is easy to over-complicate the display. We propose a form of display that is more easily read.

Design

In diabetes, long term control of blood glucose within limits is associated with fewer complications [3]. This requires the ability to monitor glucose levels outside the clinic quickly. Development of CGM was a significant advance in diabetes control [3]. Good control requires accurate data, allowing a timely response to changes.

The first commercial CGM system was approved in 1999 [3]. It measures interstitial glucose concentrations every minute and records values every fifteen. It gives an instantaneous value and the direction of travel. The manufacturer's software displays the summary data as a time-series, it also estimates a value for the Haemoglobin A1c (HbA1c) [5] this is the usual method, [6]. Figure 1a represents a summary generated by the manufacturer; showing seven days of glucose readings separately, they also combine the daily data into a single plot across a single 24 hours (Figure 1b). A single reading is plotted as a point on the graph. Changes from the median and the variability can be hard to interpret, as deviations are laid on top of each other and a daily patterns are obscured. An observer can see peaks at the same time of day, but they cannot tell if it occurs on successive days, or if the differences are on weekdays or only on weekends. Placing the data in a spiral them allows the observer to not only discern the main pattern, but if they chose to refer week to week they could see patterns relating to the individual weekend days.

In our proposed design, the data are arranged in a spiral of seven turns corresponding to a week's data, each day is a full turn. It uses a limited range of colours to map to the glucose levels. This simplifies the data and facilitates straightforward comparisons. Trends can be seen within the day, regular deviations from target at specific times of day across the week and differences between weekdays and the weekend can be observed.

METHODS

Figure 1c shows the proposed way to represent the same data as Figure 1a/b. One turn is a day which begins at midnight (top) and the week spirals into the centre. Bands of colour represent target zones. A five colour system was chosen to allow the observer to concentrate on the timing of the deviations from the target zone: Green (target zone; 5 to 8 mmol/l), yellow (3 to 5 mmol/l) is slightly below and red (<3 mmol/l) is strongly hypoglycaemic. Cyan (8 to 11 mmol/l) and blue (>11 mmol/l) are slightly and very hyperglycaemic (values are from the standard settings of the system, [5]). The advantage is that repeated deviations from the target show the same colour and in the same quadrant (more blue in the top right quadrant, between midnight and six, Figure 1c). The observer can concentrate on the timing of deviations. The weekend is the innermost spirals, differences in habits are apparent.

Data sources

Data was recorded by the author (PJK) on his personal CGM system, between 2017 and 2021 and represent his glucose levels. He has had Type 1 diabetes since 1983.

Continuous Glucose Monitor These data were taken from an Abbott Freestyle, Versions 1 and 2 (Abbott Diabetes Care Limited, UK). The data is quoted to a resolution of 0.05 mm/l. Studies have found the mean absolute relative difference between the Libre sensor and capillary blood glucose measurements was 13.2% [7]. All estimates of HbA1cs are taken from the software (FreeStyle, Version 1 [8]).

Spirals The display was written in Matlab (Mathworks, USA). Each event is plotted as a point in a spiral with the colour mapped to the glucose level as described above and with a key top right of every figure. Every turn in the spiral has 96 elements (one point every 15 minutes over 24 hours).

Interpretation

In Figure 1c, the impression gained is that most of the time the colours are light (cyan, yellow and green), thus the control is either in the target zone, or close to it. What is easily discerned are the extreme deviations (red and blue) and if there were any patterns in behaviour.

The observer can see the outer cycle (Monday) was broadly between 3 and 11 mmol/l, and mostly within the target zone (green). However, in late morning (bottom) for over two hours, levels were over 11 mmol/l (blue). From around 3 am on Wednesday there was a low of less than 3 mmol/l (red). During the early hours of Thursday and Friday there are highs (top right, blue) following a low (and over correction) over Wednesday night (yellow and red).

RESULTS

The following are examples, taken from user data; the advantages of this method are described to show how the display assists in easy interpretation of trends and facilitates planning.

Extremes

Figure 2 shows two weeks with extremes of control. The choice of specific weeks is based on manufacturer's estimates of HbA1c for each week.

Figure 2 demonstrates the ease of analysis of the week's data quickly. A superficial inspection of the right spiral, shows a large number of instances with glucose above 11 mmol/l and only two instances of hypoglycaemic events. The majority of the rest of the week being mostly above 8 mmol/l. Better control (left) is predominantly green or yellow with few instances of above 11 mmol/l or below 3 mmol/l. What is clear is that in the poorer week, the excursions over 11 mmol/l are long and sustained and betray insufficient insulin during this time.

Daily events

Figure 3 demonstrates patterns of behaviour. Of interest are two periods: The first is a peak in glucose following breakfast from Thursday to Sunday, starting at 8am and ending before noon. The second is a low period on all days (except Sunday) from noon until 1pm, when food was consumed. Sunday morning activity was a long run after a larger breakfast (and a lower dosage of insulin). On other days, a smaller breakfast and an earlier injection of fast acting insulin, reduced the post-breakfast peak. The innermost turns of the spiral reveal differences in the subject's habit between work and weekends.

Consecutive weeks

Figure 4 shows consecutive weeks; in the first week, there are numerous instances of higher levels. Post noon peaks Monday to Wednesday, improve towards the end of the week, (following remedial action). Night-time levels are high, which results in peaks after breakfast. However, they are the result of poorer selection of dose and food resulting in weaker control in the evening of the day before. In this display, analysis can be made without the interruption of the edge of the chart. The benefit of viewing the data in this form rather than as individual plots separated at midnight, is that we can see that these night-time highs are the result of actions in the evening of the day before. In a conventional display, each day broken up and the link to the next day is severed. Displayed this way it is clear that one day's control links to the preceding day.

Limitations

The aim of the change was to reduce the complexity in order to simplify the display. This means there is some loss of information. Early attempts to include the timing of injections, meals or exercise obscured the patterns displayed, they were therefore excluded from the display. Future work will be in investigate further ways to indicate important events. This is a two dimensional mapping of three dimensional data, however it is believed that a 3D display (which is entirely possible) would not result in any greater insights.

This is only the simplest use of this techniques. Work by one of the authors with other forms of data is exploring use of multiple weeks on a same display [9 REF TO ALIX'S OTHER PAPERS]. It would be possible to display the same day of the week on consecutive spirals to explore weekend patterns etcetera.

CONCLUSION

Glucose readings derived from a CGM system can be mapped onto a spiral that represents a week with one turn per day. This creates a display that is simple and easy to interpret. It allows patterns in glucose levels at times of day or week to be observed. This improved visibility should allow better control by patients.

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Figures

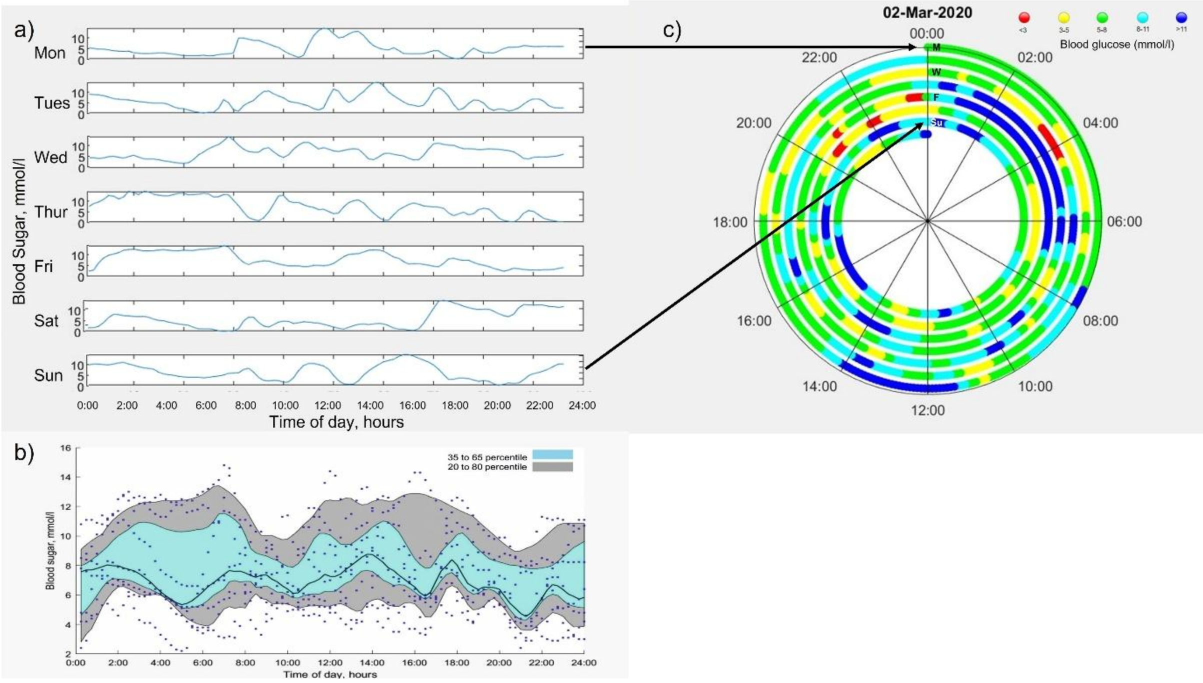

Figure 1: An example of a weeks data from a subject. a) Conventional time series plot. Each day is presented separately (top), then the summary data across the week is presented b). The median is presented as a black line. The 35th to 65th percentile is in cyan, and the 20th to 80th percentile is in grey. c) The same data as a spiral plot. Midnight at the top and a week is seven clockwise turns inward. Blood sugar levels indicated by colour on the spiral (see key).

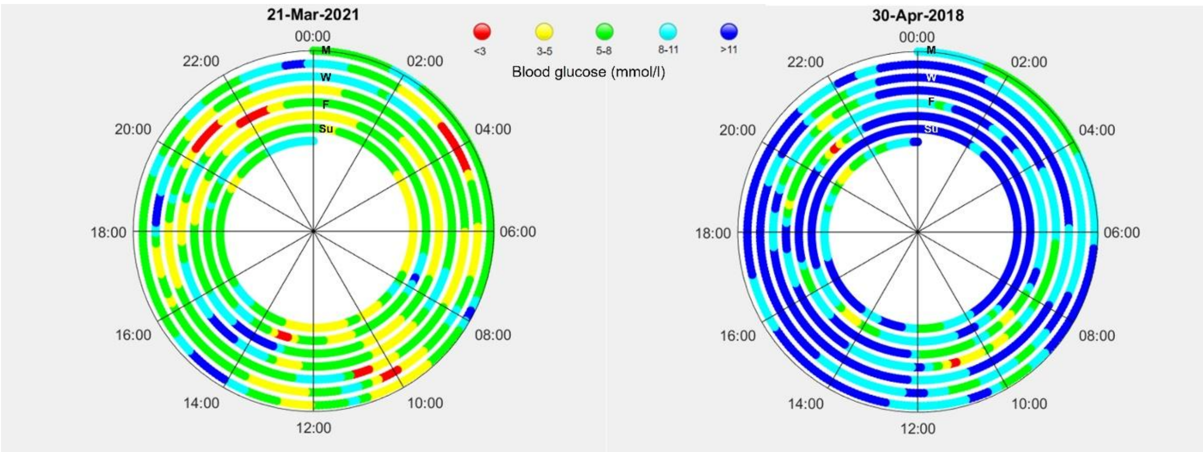

Figure 2: An an example of the ease with which the overall weekly trends can be observed. The left had a estimated HbA1cs of 5.3% while the week on the right was 8.6%. The right is darker and more extreme than the left plot.

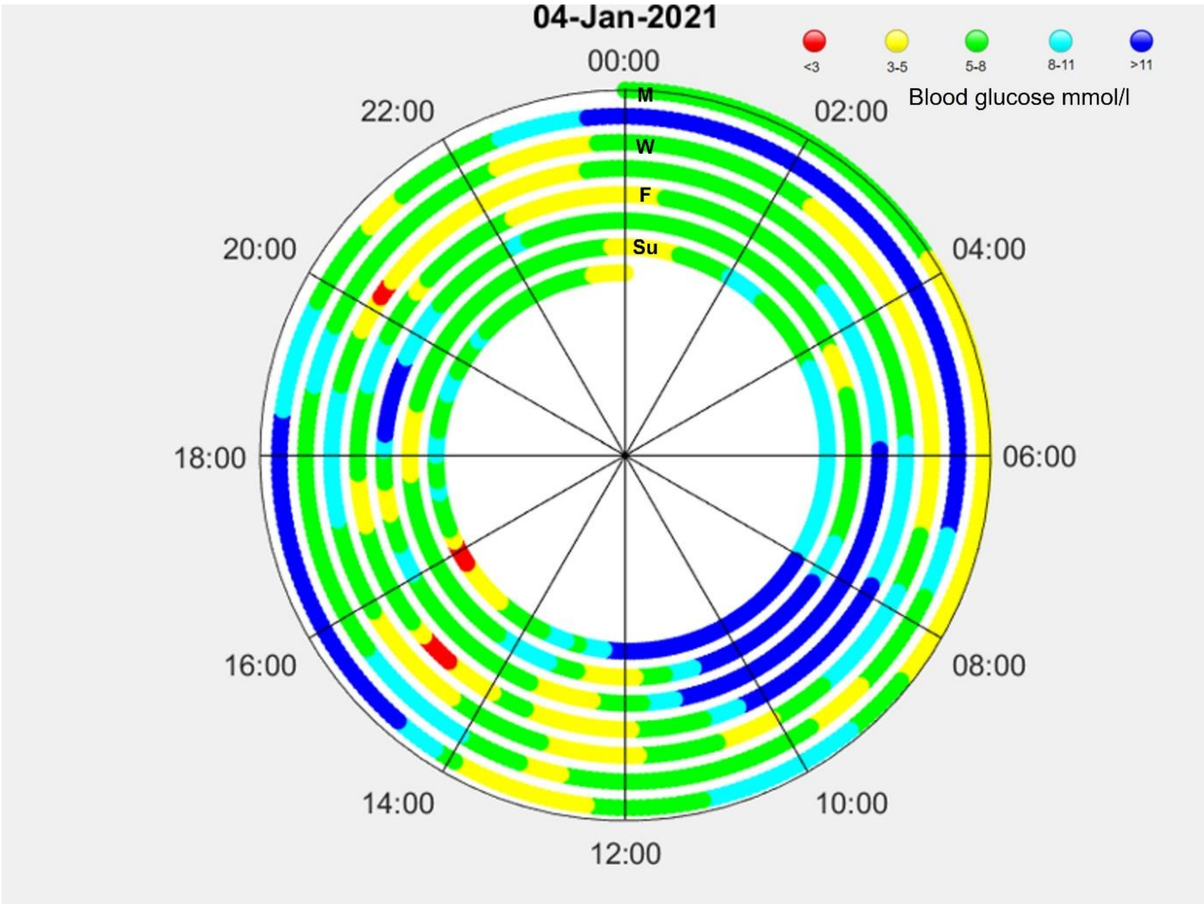

Figure 3: This plot shows four days with a peak after breakfast on Thursday to Sunday (eight am to noon lower right quadrant). The week's HbA1c was 6.3%. Note: The lower glucose levels before lunch during weekdays required a snack around 10am.

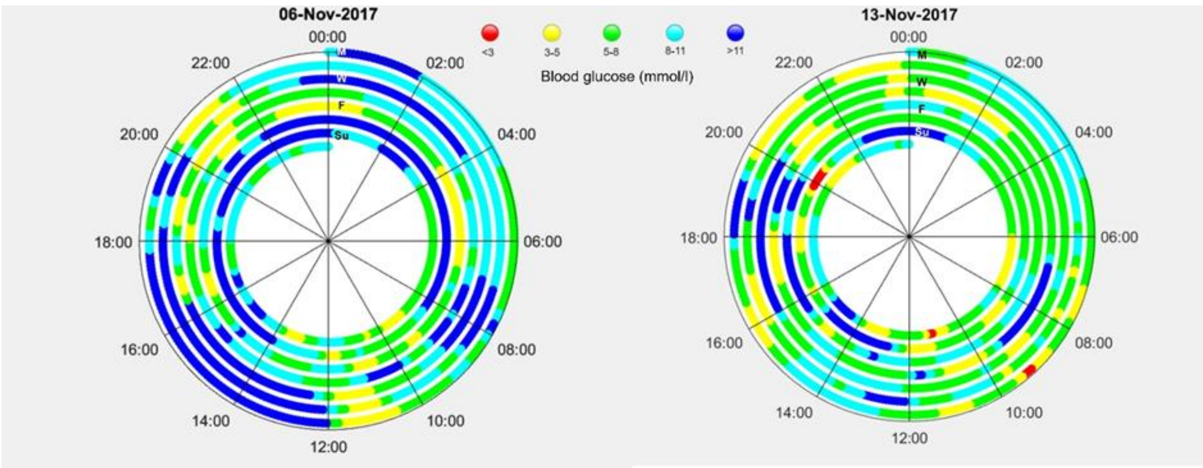

Figure 4: Two consecutive weeks showing the result of efforts to keep the overall blood sugar levels down while ensuring the variations are also as small as practical. First week (left) has a higher estimated HbA1c (7.5%). Night time highs result in post breakfast peaks at 7am. The advantage of the continuous display can be easily seen as one day's control impacts on the next day's levels conventional graphical display would break the line at midnight..