Diametrics

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Title Page

Title

Diametrics: A User-Friendly Web Tool for Custom Analysis of Continuous Glucose Monitoring Data

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Abbreviations

ADA - American Diabetes Association

AUC - Area Under the Curve

CGM - Continuous Glucose Monitoring

EXTOD - Exercise in Type 1 Diabetes

JCHR - Jaeb Center for Health Research

MOTIVATE-T2D - Mobile Health Biometrics to Enhance Exercise and Physical Activity Adherence in Type 2 Diabetes

T1-DEXI - Type 1 Diabetes EXercise Initiative

T1-DEXIP - Type 1 Diabetes EXercise Initiative Pediatric

Key words

1. Continuous Glucose Monitoring (CGM)
2. Web Application
3. Glycemic Analysis
4. Event-specific Analysis
5. Metrics
6. Open-source

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During the course of preparing this work, the authors used ChatGPT and Copilot for the purpose of summarizing research papers, text editing, and providing code snippets. Following the use of this

tool/service, the authors formally reviewed the content for its accuracy and edited it as necessary. The authors take full responsibility for all the content of this publication.
Figures and table count
7 figures, 3 tables

Abstract

Background: Continuous Glucose Monitoring (CGM) systems have revolutionized diabetes management by providing real-time blood glucose tracking. However, there is a need for openly accessible tools that can analyze CGM data in relation to specific events like meals or exercise, which often require extensive technical skills to interpret, thus restricting its broader use among researchers and clinicians. Developing user-friendly web applications to facilitate this analysis could significantly broaden accessibility and utility.

Method: *Diametrics* was built with a focus on ease-of-use and versatility. The application's efficacy was validated against *iglu*, an established *R* tool with a no-code web app for CGM analysis, using data from 418 participants from three studies. The unique period-specific analysis feature was demonstrated through an illustrative case study.

Results: *Diametrics* proved effective at replicated established CGM metrics, demonstrating high concordance with *iglu*. The platform supports a wide range of CGM devices, accommodates data in various formats, and offers extensive customization in the analysis settings. The case study highlighted *Diametrics'* ability to integrate exercise-related data with CGM readings, enabling detailed analyses of how different exercise types, intensities, and times of day impact glucose levels.

Conclusions: *Diametrics* is a freely available, reproducible, user-friendly, and accurate web-based tool for CGM data analysis with a unique capability to analyze data over specific time periods. With its intuitive design and open-source accessibility, *Diametrics* provides a valuable resource in diabetes research and management, empowering users of various technical levels to perform complex analyses with ease.

Introduction

Continuous glucose monitoring (CGM) has transformed diabetes management by enabling real-time tracking of blood glucose levels and is becoming increasingly central in the management of both type 1 and type 2 diabetes (1,2). CGM devices not only allow for better daily management decisions regarding diet, medication, and lifestyle (3) but also offer researchers unprecedented data to study diabetes.

Recent advances in CGM technology have opened new research avenues focused on understanding the impact of specific events or interventions on blood glucose levels (4–13). This ability to analyze data around particular events such as meals or exercise is crucial for uncovering the nuanced effects of lifestyle factors and physiological changes on glucose control. However, the complexity of such detailed analyses often requires technical (coding) expertise, limiting access for many researchers.

Web applications (apps) offer a user-friendly solution to this challenge, requiring minimal technical skills and offering direct access through any web browser without the need for downloads. Currently, three web apps exist for CGM data analysis, offering varying degrees of complexity and functionality (14–16). These tools, however, lack the flexibility needed for in-depth examination of specific data segments, such as postprandial periods, stages of pregnancy, or exercise, thus restricting deeper insights into short-term glycemic responses around specific events.

In this paper, we introduce *Diametrics*, a novel web application designed specifically to address this need. We will validate its performance against *iglu* (14), an established *R* package for CGM data analysis that includes a web application interface. Finally, through a detailed case study, we will demonstrate how *Diametrics* can be used to analyze CGM data over specific time windows in order to closely examine glucose fluctuations around recorded events.

Methods

Software

Diametrics was developed using *Python 3.9*. The application's architecture is designed using *Dash 2.7* (17) to be user-friendly, ensuring ease of navigation and interaction for users with varying levels of technical expertise. *Diametrics* is available as a free, open-source tool at diametrics.org. All code is available in a GitHub repository at github.com/cafoala/diametrics-webapp. *Diametrics* is also available as a Python package (18).

Validation

In our validation process, we utilized data from three separate studies, totalling 418 participants. The Mobile Health Biometrics to Enhance Exercise and Physical Activity Adherence in Type 2 Diabetes (MOTIVATE-T2D) study (19) included 118 individuals with type 2 diabetes from the UK and Canada, who were provided with the FreeStyle Libre Pro CGM system and participated in a prescribed exercise program. We used two weeks of baseline CGM data for each participant. Additionally, we included two studies conducted by the Jaeb Center for Health Research (JCHR): the Type 1 Diabetes EXercise Initiative (T1-DEXI) Study (11), and the Type 1 Diabetes EXercise Initiative Pediatric (T1-DEXIP) study (12), which explore exercise in adults and adolescents with type 1 diabetes, respectively. Participants wore a Dexcom G6 CGM system for 28 days and 10 days, respectively. We randomly selected 150 participants from each of the two JCHR studies.

To validate our tool, we calculated 13 different metrics (Table 1) using both *Diametrics* and *iglu's R* package (14). We chose the *iglu* R package as the benchmark for validation due to its thorough validation, comprehensive documentation, and its wide recognition in the field as evidenced by numerous citations. The metrics include all those recommended in the American Diabetes Association (ADA)'s International Consensus on the Use of Continuous Glucose Monitoring (20) and the Clinical Targets for Continuous Glucose Monitoring Data Interpretation (21), with the exception of the number of hypo- and hyper-glycemic events. We found the definition of how to calculate these events to be ambiguous in both the International Consensus (20) and the Clinical Targets (21), a limitation also noted by the iglu team (22), and thus we chose to exclude them.

We compared the metrics from each tool using Pearson correlation coefficients and Bland-Altman plots. This enabled us to quantitatively assess the degree of correlation and agreement between the two sets of results, thereby providing a robust measure of *Diametrics'* validity and reliability in analyzing CGM data across different studies and devices.

By validating *Diametrics* against *iglu*, this also demonstrates concordance between *Diametrics* and the *cgmanalysis* (23) and *CGManalyzer* (24) packages, since *iglu* has been previously validated against them (14).

Case study

To showcase the capabilities of *Diametrics* to perform in-depth data analysis into specific time windows, we present an illustrative example. To our knowledge, the analysis undertaken in this example cannot be replicated using any other available web app without technical ability or significant data processing by the user.

In this analysis, we used data from a study conducted by Exercise in Type 1 Diabetes (EXTOD) (25). In the trial, 34 participants with type 1 diabetes were monitored for eight weeks as they trained for an endurance running event. They wore FreeStyle Libre CGMs and recorded their exercise in a diary.

For this case study, we explored glucose dynamics during exercise and in the three hours prior and the three hours post-exercise, divided into one hour windows. We also examined how intensity (light, moderate, or vigorous), type of exercise (aerobic or anaerobic/mixed [non-aerobic]), and time of day (morning, afternoon, or evening) affects glycemic control around exercise.

We prepared the data from the exercise diary in accordance with the directions on the Diametrics documentation page, advanced analysis (diametrics.org/documentation). We included the intensity, type of exercise and time of day as additional data fields in the file. We conducted the data analysis through the *Diametrics* web app to calculate the metrics of glycemic control then downloaded the output to create a table and figure independently.

Results

Web App Functionality

An overview of the features of *Diametrics* and a comparison to the other available web apps is available in Table 2.

Diametrics is introduced on its homepage, which features a brief overview video and a navigational path to the documentation section. This section includes instructional videos detailing the app's usage, specific operational steps, frequently asked questions, and explanations of metric calculations.

When using the app there are four standard steps for analyzing the data (upload files, check data, analysis options and standard metrics) and additional steps that can be taken to visualize the data or do more advanced analysis.

Upload files

Diametrics is designed to support the upload of CGM data in various formats, including CSV, Excel, and text files, from multiple devices including Abbott, Dexcom, and Medtronic (Figure 1). Users have the flexibility to upload multiple files of any size or quantity and can directly adjust them within the application, making it suitable for handling extensive datasets. Any data uploaded by users will not be visible to developers or other users and is deleted after analysis. When uploading, the user selects the device that the data comes from, the units that glucose is measured in and the date format.

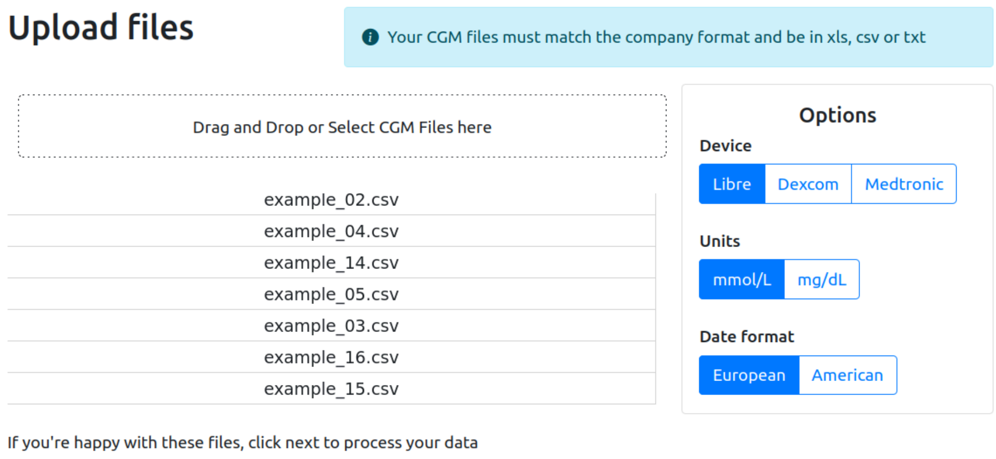
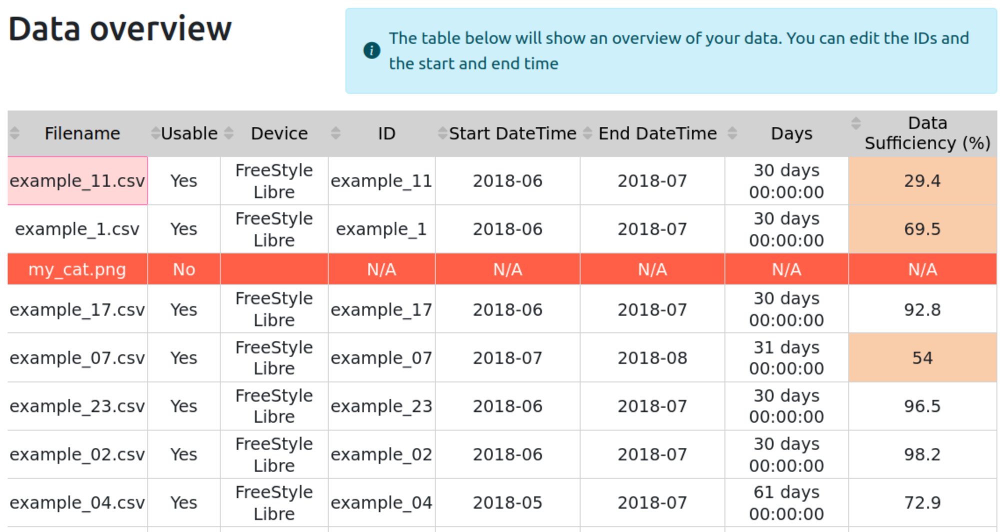


Figure 1. Uploading files to Diametrics. *Files can be uploaded in the drag and drop box and then will be displayed under "Selected files". The brand of CGM, the units and the date format are selected using the buttons under "Options".*

Check data

Once uploaded, the data is checked and displayed (Figure 2). If the data is not usable then "No" will appear in the usable column and the row will be highlighted red. The ID and start and end time of each file can be changed. If the start and end date of the file is changed, the "Days" and "Data Sufficiency (%)" columns will be updated automatically. The International consensus (20) specifies that there should be a minimum of two weeks of data with 70-80% data sufficiency. If either the number of days or the data sufficiency are below this recommendation, they will be highlighted orange to let the user know but the user can still continue with the analysis.



Filename	Usable	Device	ID	Start DateTime	End DateTime	Days	Data Sufficiency (%)
example_11.csv	Yes	FreeStyle Libre	example_11	2018-06	2018-07	30 days 00:00:00	29.4
example_1.csv	Yes	FreeStyle Libre	example_1	2018-06	2018-07	30 days 00:00:00	69.5
my_cat.png	No		N/A	N/A	N/A	N/A	N/A
example_17.csv	Yes	FreeStyle Libre	example_17	2018-06	2018-07	30 days 00:00:00	92.8
example_07.csv	Yes	FreeStyle Libre	example_07	2018-07	2018-08	31 days 00:00:00	54
example_23.csv	Yes	FreeStyle Libre	example_23	2018-06	2018-07	30 days 00:00:00	96.5
example_02.csv	Yes	FreeStyle Libre	example_02	2018-06	2018-07	30 days 00:00:00	98.2
example_04.csv	Yes	FreeStyle Libre	example_04	2018-05	2018-07	61 days 00:00:00	72.9

Figure 2. Data Validation in Diametrics. *Upon uploading, the data is assessed for usability; non-usable files are marked "No" in the usable column and highlighted in red. Users can modify the ID, start, and end times for each file, automatically updating the "Days" and "Data Sufficiency (%)" columns. Entries that don't have a minimum of two weeks of data with 70% sufficiency are highlighted in orange, though analysis can still proceed.*

Analysis options

The application aligns with ADA's International Consensus, offering all of the standard metrics of glycemic management. Flexible analysis options allow users to adjust the metrics to suit their specific needs (Figure 3). This includes the ability to fill gaps in data using interpolation (linear, cubic or Akima), adjust day/night time frames, set custom thresholds for time in range, and provide customizable definitions for glycemic events by changing the duration and threshold considered to be an event.

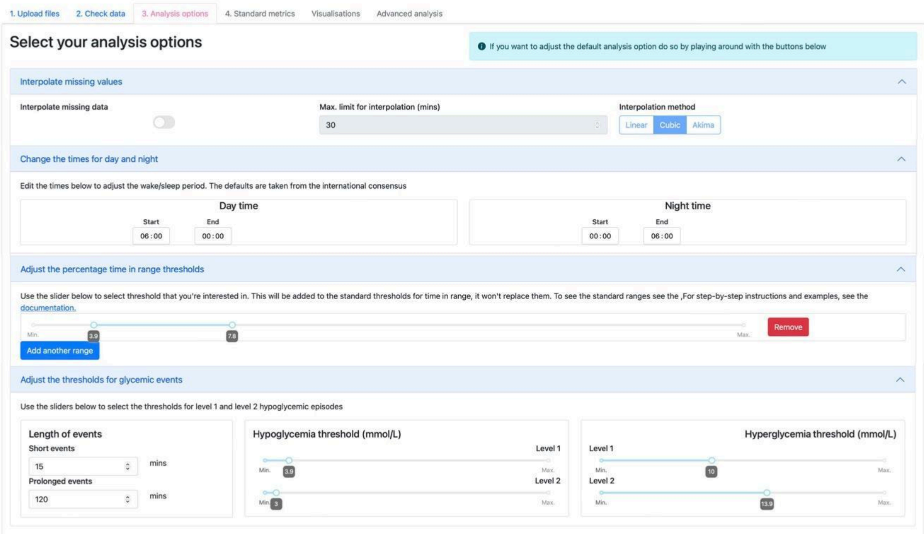


Figure 3. Selecting analysis options in Diametrics. *Users can tailor their metrics by interpolating data gaps, altering day/night time frames, setting custom thresholds for time in range, and adjusting duration and thresholds of glycemic events.*

Standard metrics

Within the web app, metrics are displayed in a table in which the data shown can be chosen, units switched between mmol/L and mg/dL and the metrics displayed for 24 hours or split by day or night (Figure 4).

Additionally, the web app allows users to customize how metrics are displayed in a table by selecting specific data to be shown, switching units between mmol/L and mg/dL, and choosing to view metrics over a 24-hour period or divided into day and night segments (Figure 4). Any user-adjusted metrics are also displayed here. Users can download their tailored tables and original combined CGM data for further analysis. Customized overview figures are automatically created to reflect the data in the table and are both interactive and downloadable.

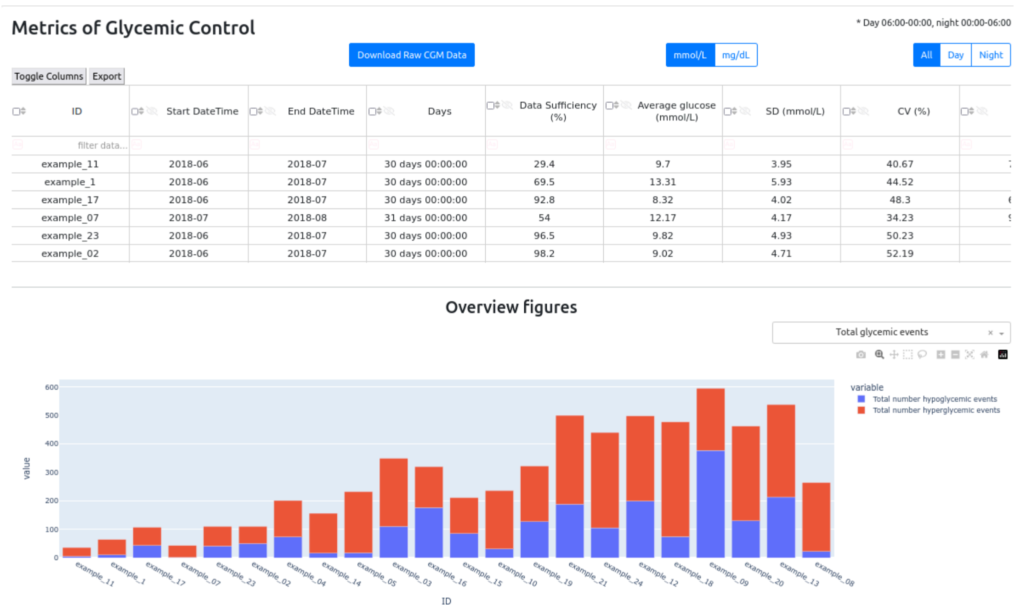


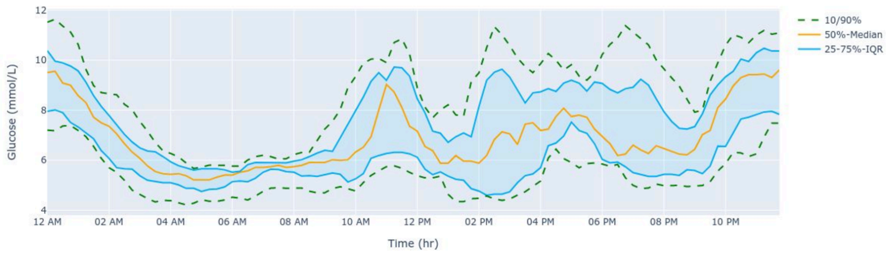
Figure 4. Calculating overview metrics and visualizations in Diametrics. *The metrics display table within the web app allows users to select data, switch units, and choose to view metrics for a 24-hour period or split by day and night. Both tailored tables and combined CGM data can be downloaded*

for further analysis. The overview figures can be changed to show different metrics, they are interactive and downloadable.

Visualizations

For data visualization, *Diametrics* offers interactive graphs and charts using *Plotly* (26), which enhances data interpretation and pattern identification. These visualizations are not only informative but also downloadable and can be manipulated by users. Two example charts are shown in Figure 5, including A) ambulatory glucose profile for one participant, and B) percentage time in range for 8 participants.

A)



B)

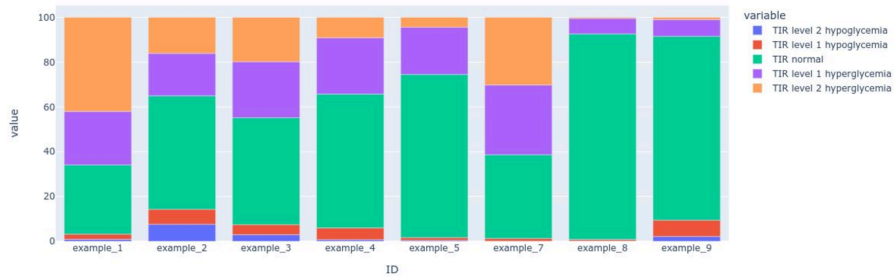


Figure 5. Examples of interactive figures available in Diametrics. *This figure showcases two of the interactive figures accessible within the Diametrics application. A) Ambulatory Glucose Profile for One Participant; a standardized graphical representation of a patient's glucose levels, typically over a 24-hour period, providing insights into patterns and variability of glucose control. The green dashed line represents the 10th and 90th*

percentiles, the orange line depicts the median glucose values, the blue shaded area represents the interquartile range.
B) Percentage Time in Range for Eight Participants; detailing the distribution of time spent in various glycemic ranges for a cohort of participants. TIR level 2 hypoglycemia, percentage of glucose readings <54 mg/dL; TIR Level 1 hypoglycemia, percentage of glucose readings between 54 mg/dL and 70 mg/dL; TIR normal: percentage of glucose readings between 70 mg/dL and 180 mg/dL; TIR level 1 hyperglycemia, percentage of glucose readings between 180 mg/dL and 250 mg/dL; and TIR level 2 hyperglycemia, percentage of glucose readings >250 mg/dL.

Advanced analysis

A key feature of *Diametrics* is its ability to perform periodic analysis, which allows users to calculate the metrics of glycemic management for specific time frames within the CGM data, such as mealtimes or exercise sessions. Users can upload a file with detailed period information and labels, and the application will link the events to the relevant CGM data and then analyze time windows around these events, calculating both standard and user-adjusted metrics for these periods.

Validation

In our validation analysis, *Diametrics* demonstrated a high degree of agreement when compared with *iglu's R* package. For 12 out of the 13 evaluated metrics, including average glucose, coefficient of variation (CV), and time in range measures, this alignment is evidenced by perfect Pearson correlation coefficients of 1 across all three studies (Table 3). The only exception was found in the metric for percentage active time/data sufficiency, which still demonstrated extremely high concordance, with Pearson correlation coefficients of 1 in the MOTIVATE-T2D study but 0.999 in both the T1-DEXI and T1-DEXIP studies.

The Bland-Altman plots also revealed a high level of agreement for all of the metrics. 11 of the 13 metrics demonstrated perfect agreement, with mean differences and limits of agreement of zero. AUC and data sufficiency were the only exceptions, displaying minimal disagreement. AUC exhibited a mean difference of 0.01 ± 0.10 (±1.95SD) (Figure 6A), and data sufficiency had a mean difference of -0.03 ± 0.46 (±1.95SD) (Figure 6A). It is important to emphasize that these slight differences have a negligible impact on the final results and do not significantly affect the overall validity of *Diametrics* in CGM data analysis.

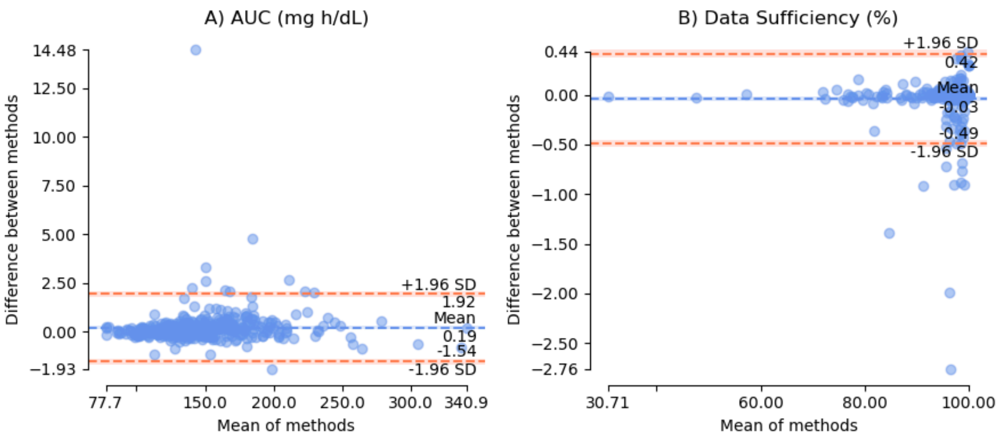


Figure 6. Bland-Altman Plots for Method Comparison in Glycemic Metrics. *This figure presents a series of Bland-Altman plots evaluating the agreement between Diametrics and iglu methods for measuring various glycemic metrics for all three studies. Each plot illustrates the difference between the methods against the average of the two methods for a specific metric, with the metrics including: A) Area Under the Curve (AUC) measured*

in mg/dL, B) Data Sufficiency, representing the percentage of time with sufficient data. All other metrics demonstrated perfect agreement, with mean difference and limits of agreement of zero. The dashed lines represent the limits of agreement (mean difference ± 1.96 standard deviation [SD]), providing a visual interpretation of the consistency between the two measurement methods. Points that lie within these limits are considered to have acceptable agreement. The mean difference (bias) is depicted by the solid orange line.

Case study

The results of the case study demonstrate the capabilities of *Diametrics* for detailed data analysis. A video of the worked case study is available at https://www.youtube.com/watch?v=bfiQRGhCLh4&t=26s.

Using the *Diametrics* web app, we were able to easily upload all CGM files simultaneously in their original downloaded format. We then set the options to match, in this case selecting FreeStyle Libre, mmol/L and European date format. Next, using the data overview section, we standardized the start and end times, which allowed for a consistent comparison of glycemic control across participants and assessed the data sufficiency of each participant to ensure the reliability of our analysis. We calculated comprehensive metrics of glycemic control for each subject, capturing the overarching patterns of glucose regulation and creating both group and individual visualizations.

Using the advanced analysis section, we uploaded an additional file containing exercise information in the compatible format. This included the start date and time of exercise, duration of exercise and three label columns identifying the time of day, type and intensity of exercise. Using only *Diametrics'* built-in functionalities, we computed the metrics for each exercise session and the respective three-hour windows pre- and post-exercise, segmented into hourly intervals. We could then download the results from *Diametrics* in order to explore variations in average glucose levels across the three-hour periods.

The observed trends in Figure 7 demonstrate a distinctive fluctuation in blood glucose levels surrounding exercise. Notably, there is an elevation in glucose concentrations leading up to the exercise period, suggestive of anticipatory action from the participants to prevent exercise-induced hypoglycemia. This is succeeded by a marked decrease post-exercise, with the most pronounced reduction occurring within the first hour following the exercise session. This pattern appears consistent across different types of exercise, intensities and times of day. There also appears to be a trend of higher glucose with higher intensity and highest glucose levels in the afternoon.

This real-world case study, derived using *Diametrics*, offers clear insights into exercise-induced changes in glucose control. It demonstrates how, without the need for complex coding or data analysis skills, one can uncover significant trends in glucose fluctuations associated with life events

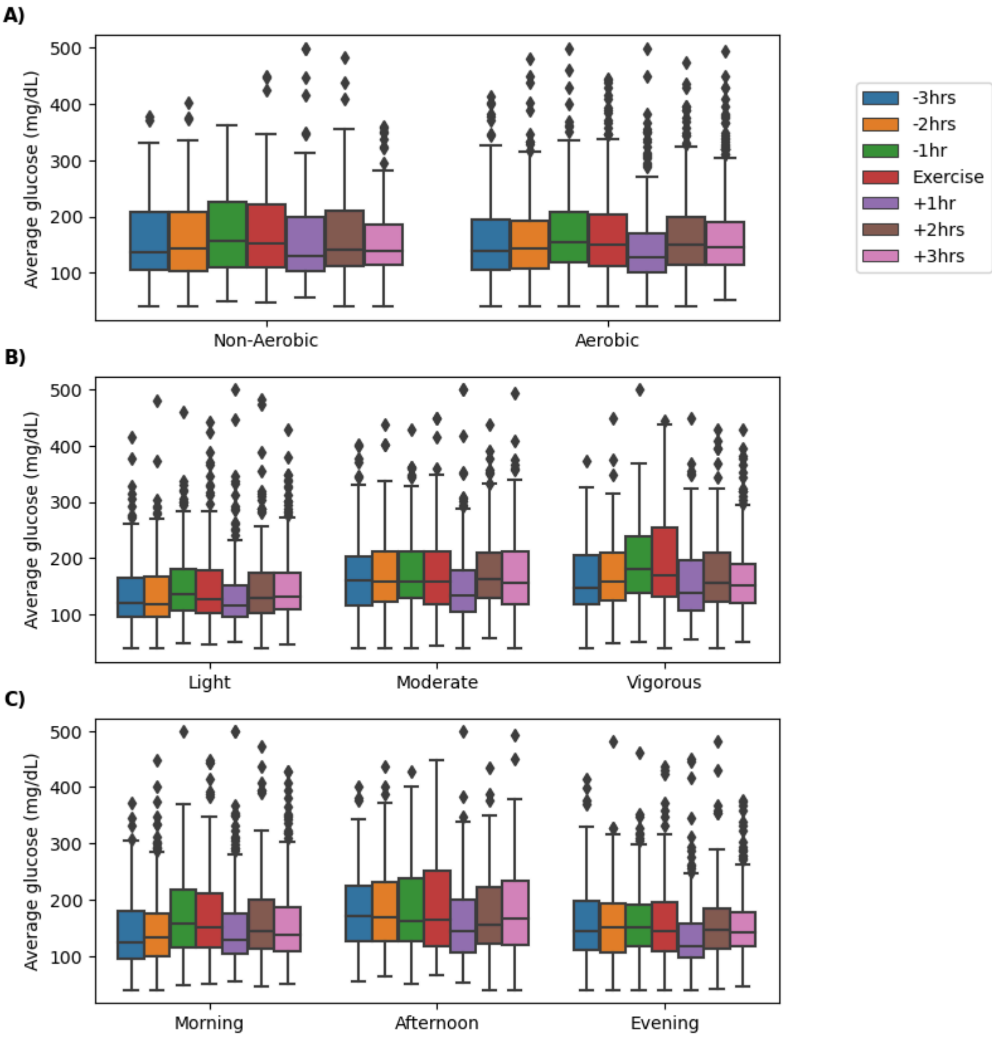


Figure 7. Impact of Exercise on Average Glucose Levels Before and After Exercise. *Box-and-whisker plots displaying the distribution of average glucose levels (mmol/L) for 34 participants from the EXTOD 101 study for the three hours before and after an exercise bout, segmented into one-hour blocks. The periods are labeled as -3hrs (3 to 2 hours before exercise), -2hrs (2 to 1 hour before exercise), -1hr (1 hour before exercise), Exercise (during exercise), +1hr (end of exercise to 1 hour after exercise), +2hrs (1 to 2 hours after exercise), and +3hrs (2 to 3 hours after exercise). Figure A) shows these results divided into the type of exercise, B) divided by intensity, and C) by the time of day.*

Discussion

In this study, we introduced, validated, and demonstrated *Diametrics*, a novel web application designed for advanced analysis of CGM data. *Diametrics* is a versatile data analysis tool offering multi-format data upload, comprehensive metrics calculation, customizable analysis options, period-specific analysis, and interactive visualizations. We validated *Diametrics* against *iglu* using CGM data from three distinct studies with a total of 418 participants, demonstrating *Diametrics'* accuracy in replicating established metrics set out in the International Consensus on the Use of Continuous Glucose Monitoring (20). Furthermore, *Diametrics'* unique feature of analyzing specific periods within CGM data was showcased through an illustrative case study, highlighting its potential to provide detailed insights into glycemic control during specific events, in this case exercise.

In comparison with existing no-code CGM analysis tools, *Diametrics* offers several advantages. As shown in Table 2, *Diametrics* provides additional features including easy unit switching, adjustable thresholds for time in range, and customizable definitions for glycemic events. Unlike most other CGM tools, it allows for the analysis of multiple periods within the CGM data, a feature particularly beneficial for detailed research studies and personalized diabetes management.

Comprehensive validation is crucial for ensuring the accuracy and reliability of digital platforms that calculate the metrics of glycemic control, given the widespread use of these metrics and their critical role in diabetes management and research. Our validation process compared metrics calculated using *Diametrics* against the *iglu* package. This package has been previously validated and as such was a robust choice as a comparator. We observed a high degree of concordance, with the only distinctions stemming from negligible variances in data sufficiency, which can likely be attributed to minor variations in the methodology employed to compute this metric. This was further corroborated by high agreement in the Bland-Altman plots. The consistency of these results across diverse studies, including MOTIVATE-T2D, T1-DEXI, and T1-DEXIP, demonstrates the robustness of *Diametrics*, particularly considering the range of participants and devices involved.

Additionally, the accessibility and adaptability of *Diametrics* are particularly significant. Metrics of glycemic control are frequently used by researchers but calculating them often requires considerable technical expertise. *Diametrics* addresses this challenge by offering a platform that simplifies these complex analyses, enabling researchers with varying levels of technical skill to engage deeply with CGM data.

The capacity to link event data, including dietary intake, physical activity, and phases of the menstrual cycle, directly to CGM data represents an advancement in diabetes management and research. This interconnectivity enables patients and healthcare providers to discern the immediate and delayed effects of lifestyle choices and phase of menstrual cycle on blood glucose levels, offering a more personalized and responsive approach to diabetes care.

From a research perspective, the amalgamation of lifestyle factors with CGM data opens new avenues for investigating the complex interplay between daily activities and diabetes management. It allows for the study of how specific interventions or behaviors correlate with glycemic outcomes in real-world settings, enhancing our understanding of effective diabetes management strategies.

Diametrics' open-access and open-source approach ensures it remains current and aligned with the dynamic landscape of diabetes research and management. The importance of open-source platforms lies in their ability to foster innovation and collaborative development, inviting contributions from the worldwide community.

While *Diametrics* shows potential, it's important to acknowledge its limitations. The validation process, though thorough, was limited to specific datasets (MOTIVATE-T2D, T1-DEXI and T1-DEXIP), which may not cover all potential use cases. Future studies could expand the range of data and scenarios tested to ensure broader applicability. Additionally, as with any software tool, there is a need for continuous updates and improvements based on user feedback and technological advancements. Future versions of *Diametrics* could incorporate more advanced analytics features or integrate machine learning algorithms to predict glucose level trends, enhancing its utility in diabetes management.

Conclusion

In conclusion, Diametrics is a freely available, accurate, and user-friendly web application for CGM data analysis with additional features not typically found in other CGM analysis tools. It enables quick and easy calculation of all the standard metrics of glycemic control for large amounts of data, provides options for user customization, allows for easy toggling between glucose measurement units, and crucially, facilitates in-depth period-specific analysis by linking glucose data with specific events such as meals or exercise. Consequently, Diametrics could help to support individuals with diabetes, healthcare providers, and researchers by enhancing their understanding of how specific events influence glucose levels and aiding in the improvement of diabetes management.

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Tables

Metric	Description	Calculation method
Data Sufficiency	Percentage of data available for analysis.	$\frac{Number\ of\ valid\ glucose\ readings}{Total\ possible\ readings} \times 100$
Percentage Time in Normal Range	Percentage of readings where glucose levels are in normal range (70-180 mg/dL).	$\frac{Readings \in (70, 180)\ mg/dL}{Number\ of\ readings} \times 100$
Percentage Time in Hypoglycemia	Percentage of readings where glucose levels are in hypoglycemia (70 mg/dL).	$\frac{Readings < 70\ mg/dL}{Number\ of\ readings} \times 100$
Percentage Time in Hyperglycemia	Percentage of readings where glucose levels are in hyperglycemia (>180 mg/dL).	$\frac{Readings > 180\ mg/dL}{Number\ of\ readings} \times 100$
Average Glucose	Mean of all glucose readings.	$\frac{\Sigma\ Glucose\ readings}{Number\ of\ readings}$
Standard Deviation (SD)	Measure of the glucose reading variability.	$\sqrt{\frac{\Sigma\ (Glucose\ reading - Average\ glucose)^2}{n-1}}$
Coefficient of Variation (CV)	Relative measure of glucose reading variability.	$\frac{Standard\ deviation}{Average\ glucose} \times 100$
Estimated hbA1c (eA1c)	Estimated average glucose over the past 2-3 months.	$\frac{28.7 \times Average\ glucose\ (mg/dL) + 46.7}{1.59}$
Low Blood Glucose Index (LBGI)	Measure of frequency and extent of hypoglycemia	$\sum_{i=1}^{n}\left(1.1 - \left(\frac{glucose_i}{100}\right)^2\right)$ for readings <70 mg/dL
High Blood Glucose Index (HBGI)	Measure of frequency and extent of hyperglycemia	$\sum_{i=1}^{n}\left(\left(\frac{glucose_i}{100}\right)^2 - 1\right)$ for readings >180 mg/dL
Area Under the Curve (AUC)	Integral of glucose values over time, indicating overall exposure to glucose.	$\sum_{i=1}^{n-1}\frac{(glucose_i + glucose_{i+1})}{2} \times (time_{i+1} - time_i)$

Table 1. Metrics used for validation of the* Diametrics *web application.
This table offers a clear description of the 13 metrics tested in the validation and provides the corresponding mathematical formulas used for their calculation.

	Diametrics	GlyCulator	iglu	rGV
Metrics				
Number of days CGM worn	✓	✓	✓	
Active time %	✓	✓	✓	
Mean glucose	✓	✓	✓	✓
Glucose management indicator	✓	✓	✓	✓
Glycemic variability (%CV)	✓	✓	✓	✓
Time above/in/below range	✓	✓	✓	✓
Ambulatory glucose profile	✓	✓	✓	
Day and night	✓	✓	✓	
User flexibility				
Easy switch between units	✓			
Adjustable thresholds for time in range	✓	✓	✓	✓
Adjustable thresholds for glycemic events	✓		✓	
Adjustable day/night time	✓		✓	
Multiple periods selection for analysis	✓			
Calculate metrics for specific time periods	✓			
Interactive visualizations	✓			
File upload				

Medtronic	✓	✓	✓	
Abbott	✓	✓	✓	
Dexcom	✓	✓	✓	
User defined	✓	✓	✓	✓
File preparation				
Period selection for analysis	✓	✓		
Missing data imputation	✓	✓		
Multiple file processing	✓	✓	✓	
Many-to-single file merge	✓	✓		
Sharing and access				
Graphical user interface	✓	✓	✓	✓
Online platform	✓	✓	✓	✓
Programmatic access	Python	Python	R	R
Open source	✓		✓	
Source publication/code repository	This article	10.2337%2Fdc22-0534	10.1371/journal.pone.0248560	10.1177/19322968211028909

Table 2. Comparison of functionality between no-code CGM analysis web applications. *This table provides a detailed comparison of various functionalities across four no-code CGM analysis web applications: Diametrics, GlyCulator, iglu,and rGV. Each row represents a specific feature or capability, the presence of a checkmark (✓) indicates that the*

corresponding application supports the feature. The table is modified from the original version created by Chrzanowski et al. (2023).

	Study		
Metric	**MOTIVATE-T2D**	**T1-DEXI**	**T1-DEXIP**
Average glucose	1	1	1
SD	1	1	1
CV	1	1	1
eA1c	1	1	1
AUC	1	1	1
HBGI	1	1	1
LBGI	1	1	1
Time in normal range	1	1	1
Time in level 1 hyperglycemia	1	1	1
Time in level 2 hyperglycemia	1	1	1
Time in level 1 hypoglycemia	1	1	1
Time in level 2 hypoglycemia	1	1	1
Data Sufficiency/Active Time	1	0.999	0.999

Table 3. Pearson Correlation Coefficients for comparing calculations between Diametrics and IGLU for 13 common CGM metrics. *This table presents the Pearson correlation coefficients for a range of metrics comparing the results from Diametrics and iglu for the MOTIVATE-T2D, T1-DEXI and T1-DEXIP studies. The values represent the correlation between the results of the two compared methodologies across these different measures, with 1 to 3 decimal places, indicating a perfect correlation. Abbreviations: Standard Deviation (SD), Coefficient of Variation (CV), estimated A1c (eA1c), Area Under the Curve (AUC), High Blood Glucose Index (HBGI), Low Blood Glucose Index (LBGI). Time in normal range, percentage of glucose readings between 70 mg/dL and 180 mg/dL; Time in level 1 hyperglycemia, percentage of glucose readings between 180 mg/dL and 250 mg/dL; Time in level 2*

hyperglycemia, percentage of glucose readings >250 mg/dL; Time in level 1 hypoglycemia, percentage of glucose readings between 54 mg/dL and 70 mg/dL; Time in level 2 hypoglycemia, percentage of glucose readings <54 mg/dL.

percentage of glucose readings <54 mg/dL.

Figures & Legends

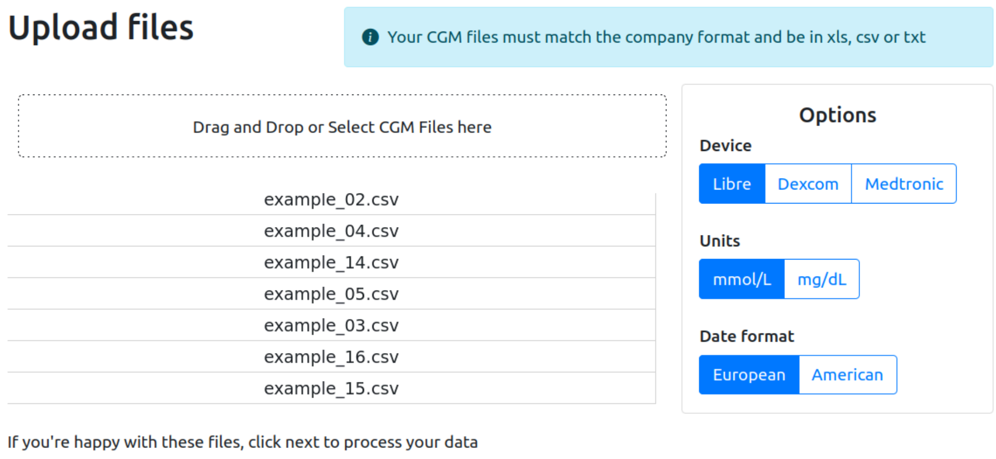
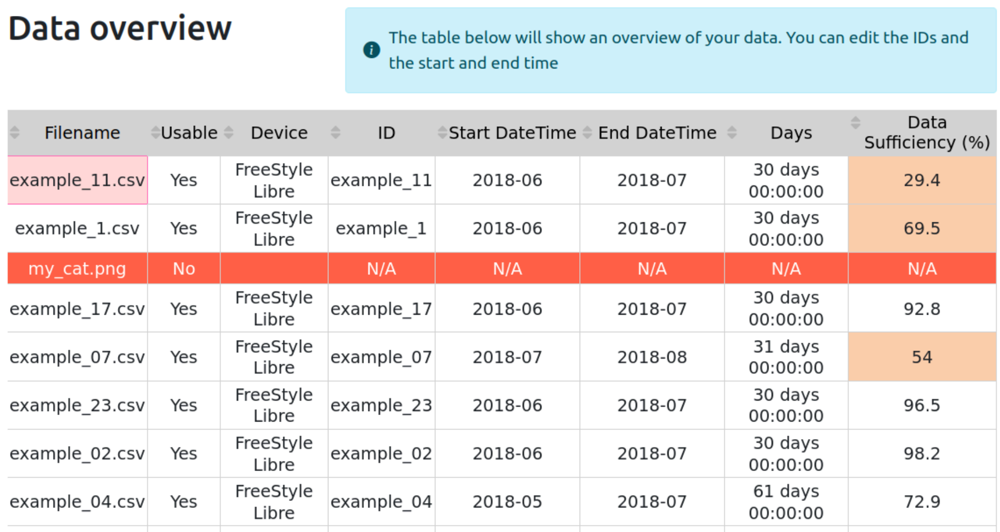


Figure 1. Uploading files to Diametrics. *Files can be uploaded in the drag and drop box and then will be displayed under "Selected files". The brand of CGM, the units and the date format are selected using the buttons under "Options".*



Filename	Usable	Device	ID	Start DateTime	End DateTime	Days	Data Sufficiency (%)
example_11.csv	Yes	FreeStyle Libre	example_11	2018-06	2018-07	30 days 00:00:00	29.4
example_1.csv	Yes	FreeStyle Libre	example_1	2018-06	2018-07	30 days 00:00:00	69.5
my_cat.png	No		N/A	N/A	N/A	N/A	N/A
example_17.csv	Yes	FreeStyle Libre	example_17	2018-06	2018-07	30 days 00:00:00	92.8
example_07.csv	Yes	FreeStyle Libre	example_07	2018-07	2018-08	31 days 00:00:00	54
example_23.csv	Yes	FreeStyle Libre	example_23	2018-06	2018-07	30 days 00:00:00	96.5
example_02.csv	Yes	FreeStyle Libre	example_02	2018-06	2018-07	30 days 00:00:00	98.2
example_04.csv	Yes	FreeStyle Libre	example_04	2018-05	2018-07	61 days 00:00:00	72.9

Figure 2. Data Validation in Diametrics. *Upon uploading, the data is assessed for usability; non-usable files are marked "No" in the usable column and highlighted in red. Users can modify the ID, start, and end times for each file, automatically updating the "Days" and "Data Sufficiency (%)" columns.*

Entries that don't have a minimum of two weeks of data with 70% sufficiency are highlighted in orange, though analysis can still proceed.

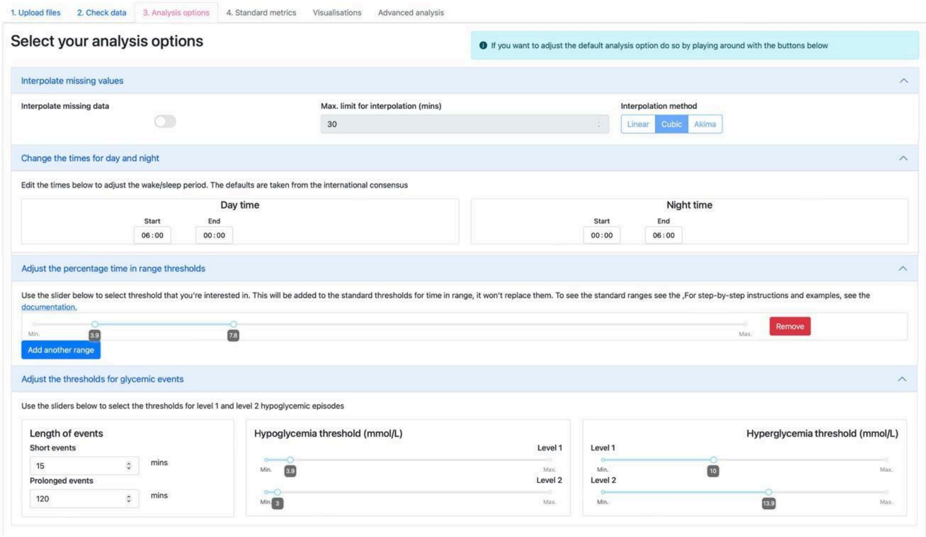


Figure 3. Selecting analysis options in Diametrics. *Users can tailor their metrics by interpolating data gaps, altering day/night time frames, setting custom thresholds for time in range, and adjusting duration and thresholds of glycemic events.*

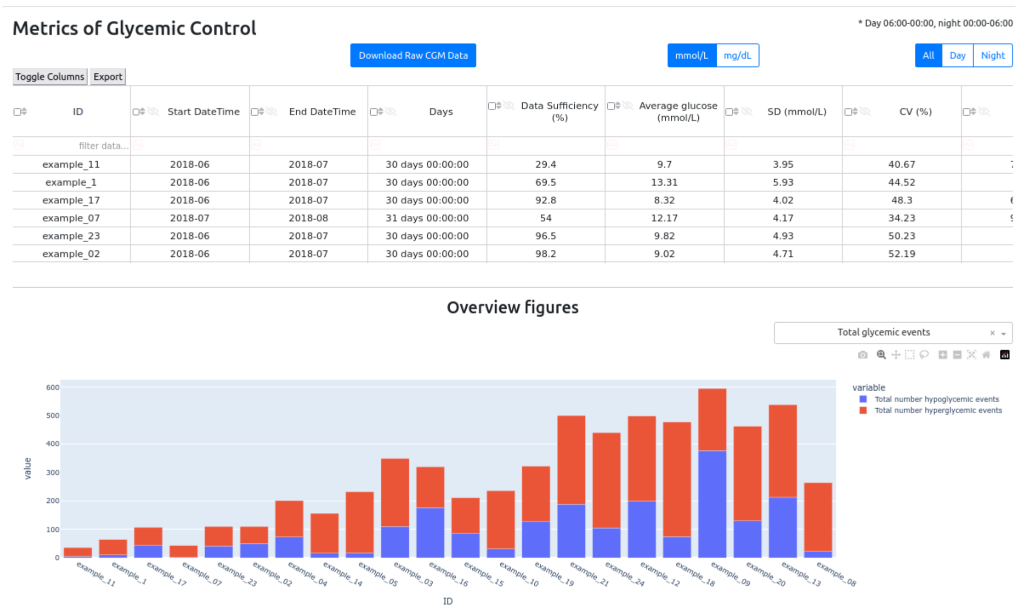
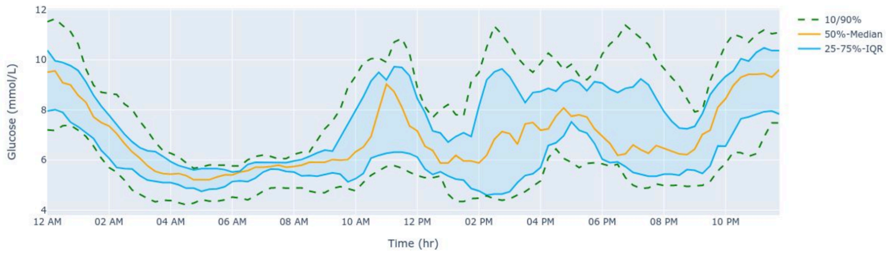


Figure 4. Calculating overview metrics and visualizations in Diametrics. *The metrics display table within the web app allows users to select data, switch units, and choose to view metrics for a 24-hour period or split by day and night. Both tailored tables and combined CGM data can be downloaded for further analysis. The overview figures can be changed to show different metrics, they are interactive and downloadable.*

A)



B)

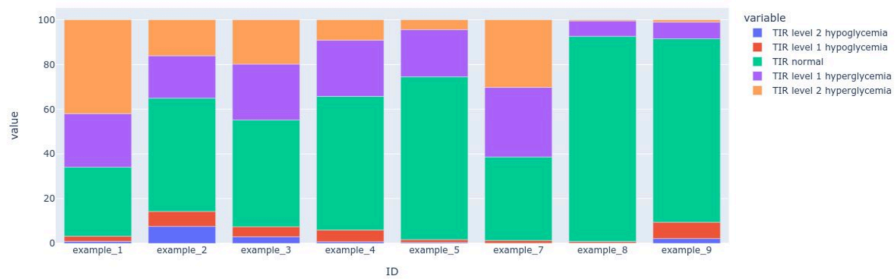


Figure 5. Examples of interactive figures available in Diametrics. *This figure showcases two of the interactive figures accessible within the Diametrics application. A) Ambulatory Glucose Profile for One Participant; a standardized graphical representation of a patient's glucose levels, typically over a 24-hour period, providing insights into patterns and variability of glucose control. The green dashed line represents the 10th and 90th percentiles, the orange line depicts the median glucose values, the blue shaded area represents the interquartile range.*

B) Percentage Time in Range for Eight Participants; detailing the distribution of time spent in various glycemic ranges for a cohort of participants. TIR level 2 hypoglycemia, percentage of glucose readings <54 mg/dL; TIR Level 1 hypoglycemia, percentage of glucose readings between 54 mg/dL and 70 *mg/dL; TIR normal: percentage of glucose readings between 70 mg/dL and 180 mg/dL; TIR level 1 hyperglycemia, percentage of glucose readings between 180 mg/dL and 250 mg/dL; and TIR level 2 hyperglycemia, percentage of glucose readings >250 mg/dL.*

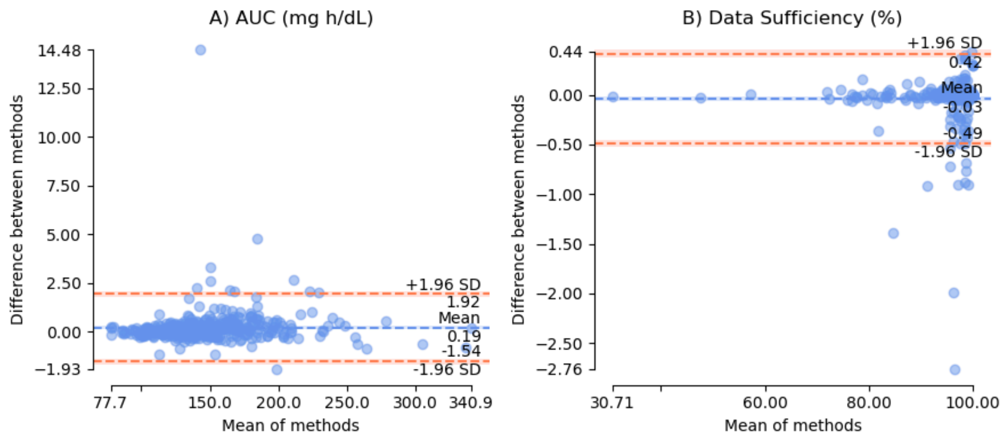


Figure 6. Bland-Altman Plots for Method Comparison in Glycemic Metrics. *This figure presents a series of Bland-Altman plots evaluating the agreement between Diametrics and iglu methods for measuring various glycemic metrics for all three studies. Each plot illustrates the difference between the methods against the average of the two methods for a specific metric, with the metrics including: A) Area Under the Curve (AUC) measured in mg/dL, B) Data Sufficiency, representing the percentage of time with sufficient data. All other metrics demonstrated perfect agreement, with mean difference and limits of agreement of zero. The dashed lines represent the limits of agreement (mean difference ± 1.96 standard deviation [SD]), providing a visual interpretation of the consistency between the two measurement methods. Points that lie within these limits are considered to have acceptable agreement. The mean difference (bias) is depicted by the solid orange line.*

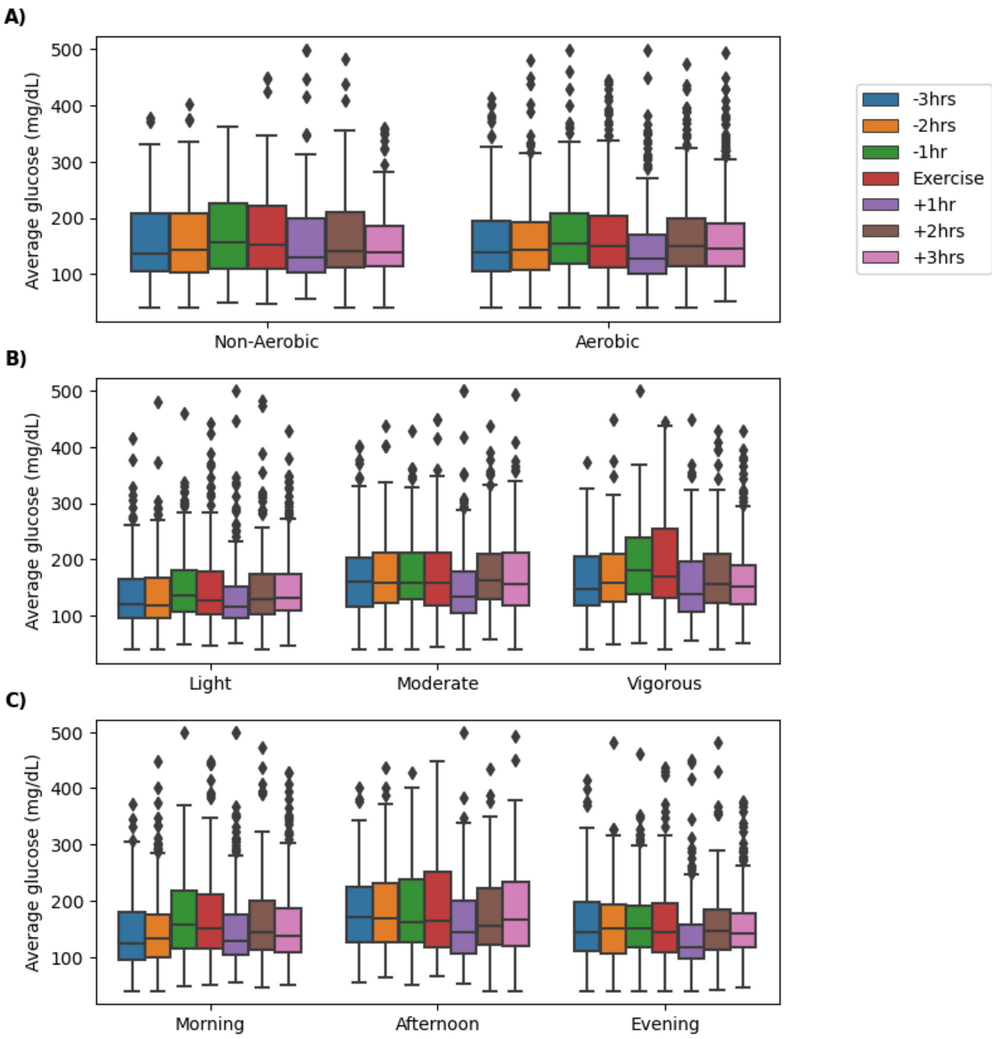
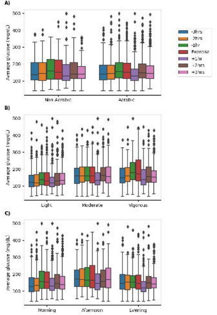
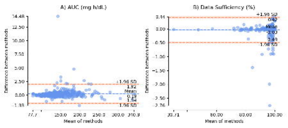


Figure 7. Impact of Exercise on Average Glucose Levels Before and After Exercise. *Box-and-whisker plots displaying the distribution of average glucose levels (mmol/L) for 34 participants from the EXTOD 101 study for the three hours before and after an exercise bout, segmented into one-hour blocks. The periods are labeled as -3hrs (3 to 2 hours before exercise), -2hrs (2 to 1 hour before exercise), -1hr (1 hour before exercise), Exercise (during exercise), +1hr (end of exercise to 1 hour after exercise), +2hrs (1 to 2 hours after exercise), and +3hrs (2 to 3 hours after exercise). Figure A) shows these results divided into the type of exercise, B) divided by intensity, and C) by the time of day.*

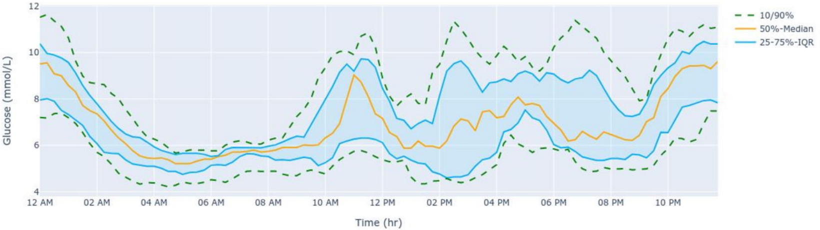


A)
-3hrs
-2hrs
-1hr
Exercise
+1hr
+2hrs
+3hrs
Average glucose (mg/dL)
500
400
300
200
100
Non Aerobic
Aerobic
B)
Average glucose (mg/dL)
Light
Moderate
Vigorous
C)
Average glucose (mg/dL)
Morning
Afternoon
Evening



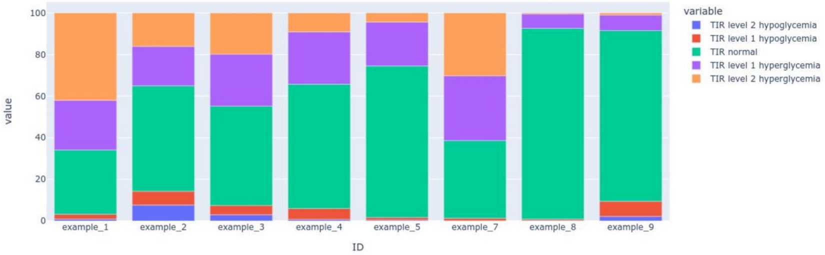
A) AUC (mg h/dL)
Difference between methods
Mean of methods
+1.96 SD
1.92
Mean
0.19
-1.96 SD
-1.54
B) Data Sufficiency (%)
Difference between methods
Mean of methods
+1.96 SD
Mean
-0.03
-1.96 SD
-0.49

A)



12
10
8
6
4
Glucose (mmol/L)
12 AM
02 AM
04 AM
06 AM
08 AM
10 AM
12 PM
02 PM
04 PM
06 PM
08 PM
10 PM
Time (hr)
10/90%
50%-Median
25-75%-IQR

B)



100
80
60
40
20
0
value
example_1
example_2
example_3
example_4
example_5
example_7
example_8
example_9
ID
variable
TIR level 2 hypoglycemia
TIR level 1 hypoglycemia
TIR normal
TIR level 1 hyperglycemia
TIR level 2 hyperglycemia

Metrics of Glycemic Control

Download Raw CGM Data

mmol/L | mg/dL

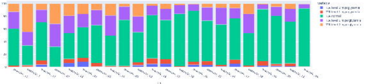
All | Day | Night

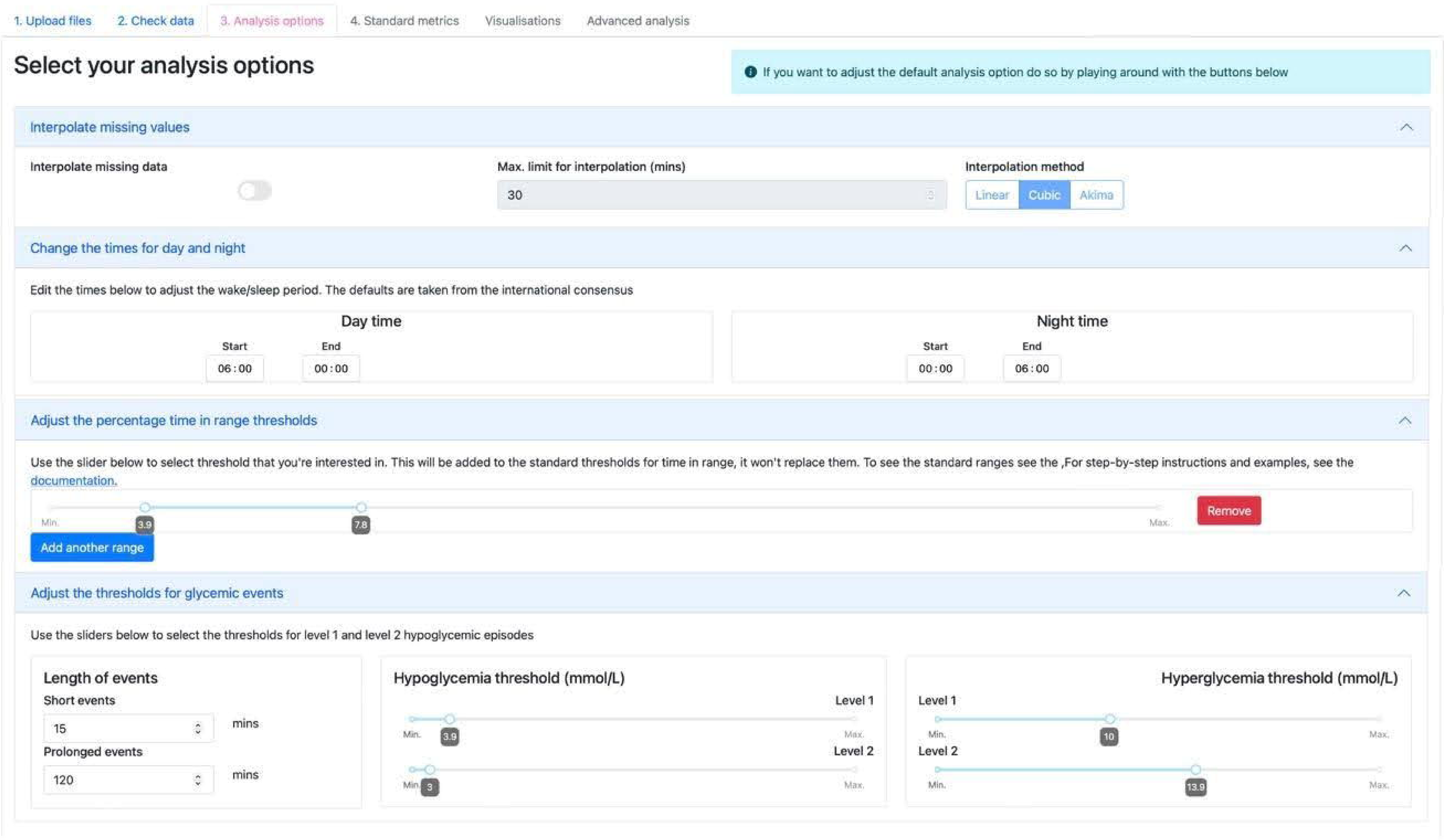
Toggle Columns | Export

ID	Start DateTime	End DateTime	Days	Data Sufficiency (%)	Average glucose (mmol/L)	SD (mmol/L)	CV (%)
example_11	2018-06	2018-07	30 days 00:00:00	29.4	9.3	3.95	40.07
example_1	2018-06	2018-07	30 days 00:00:00	63.5	13.31	5.93	44.52
example_12	2018-06	2018-07	30 days 00:00:00	92.0	8.32	4.02	48.3
example_07	2018-07	2018-08	31 days 00:00:00	54	12.17	4.17	34.23
example_23	2018-06	2018-07	30 days 00:00:00	96.5	9.02	4.90	50.23
example_02	2018-06	2018-07	30 days 00:00:00	98.2	9.02	4.71	52.19

Overview Figures

Time in range




1. Upload files
2. Check data
3. Analysis options
4. Standard metrics
Visualisations
Advanced analysis
Select your analysis options
If you want to adjust the default analysis option do so by playing around with the buttons below
Interpolate missing values
Interpolate missing data
Max. limit for interpolation (mins)
30
Interpolation method
Linear
Cubic
Akima
Change the times for day and night
Edit the times below to adjust the wake/sleep period. The defaults are taken from the international consensus
Day time
Start
06 : 00
End
00 : 00
Night time
Start
00 : 00
End
06 : 00
Adjust the percentage time in range thresholds
Use the slider below to select threshold that you're interested in. This will be added to the standard thresholds for time in range, it won't replace them. To see the standard ranges see the ,For step-by-step instructions and examples, see the documentation.
Min.
3.9
7.8
Max.
Remove
Add another range
Adjust the thresholds for glycemic events
Use the sliders below to select the thresholds for level 1 and level 2 hypoglycemic episodes
Length of events
Short events
15
mins
Prolonged events
120
mins
Hypoglycemia threshold (mmol/L)
Level 1
Min.
3.9
Max.
Level 2
Min.
3
Max.
Hyperglycemia threshold (mmol/L)
Level 1
Min.
10
Max.
Level 2
Min.
13.9
Max.

Data overview

The table below will show an overview of your data. You can edit the IDs and the start and end time

Filename	Usable	Device	ID	Start DateTime	End DateTime	Days	Data Sufficiency (%)
example_11.csv	Yes	FreeStyle Libre	example_11	2018-06	2018-07	30 days 00:00:00	29.4
example_1.csv	Yes	FreeStyle Libre	example_1	2018-06	2018-07	30 days 00:00:00	69.5
my_cat.png	No		N/A	N/A	N/A	N/A	N/A
example_17.csv	Yes	FreeStyle Libre	example_17	2018-06	2018-07	30 days 00:00:00	92.8
example_07.csv	Yes	FreeStyle Libre	example_07	2018-07	2018-08	31 days 00:00:00	54
example_23.csv	Yes	FreeStyle Libre	example_23	2018-06	2018-07	30 days 00:00:00	96.5
example_02.csv	Yes	FreeStyle Libre	example_02	2018-06	2018-07	30 days 00:00:00	98.2
example_04.csv	Yes	FreeStyle Libre	example_04	2018-05	2018-07	61 days 00:00:00	72.9

Upload files

Your CGM files must match the company format and be in xls, csv or txt

Drag and Drop or Select CGM Files here

example_02.csv
example_04.csv
example_14.csv
example_05.csv
example_03.csv
example_16.csv
example_15.csv

Options

Device

Libre | Dexcom | Medtronic

Units

mmol/L | mg/dL

Date format

European | American

If you're happy with these files, click next to process your data