

Automated Computation of Glycemic Index for Foodstuffs Using Continuous Glucose Monitoring

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Abstract

Background:

The glycemic index (GI) is a measure of the ability of a food to raise glucose levels after it is eaten. Continuous glucose monitoring (CGM) has been shown to give identical values of GI when compared to traditional methods. However, there has been no standardized protocol for measuring GI that takes into account interindividual variability and chronophysiological glycemic response to food. Our aim was (1) to create and describe software based on a Microsoft Excel 2000 spreadsheet to facilitate rapid, automated, accurate, and standardized processing of data obtained using recent CGM methodology to measure GI and its variability and (2) to assess the benefits of this new approach.

Method:

Twenty healthy subjects consumed 50 grams of glucose or four alternative foodstuffs (chocolate, apple baby food, rice squares, or yogurt) at breakfast and dinner during 1 week, resulting in 300 CGMS glucose profiles; 92% of meal tests were satisfactory for evaluation. Application and functions of the software DegifXL are described.

Results:

Using the new spreadsheet software DegifXL, time required for data processing for the 15 data sets for each subject was reduced from 2000 to 160 minutes relative to previously used manual methods. We characterized the GI for four foodstuffs with three replicate measurements in each of 20 subjects and evaluated between person, between time period, and between replicate GI variabilities.

Conclusion:

DegifXL, combined with CGM, was an efficient and effective tool for routine measurement of group- and subject-related GI.

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Abbreviations: (CGM) continuous glucose monitoring, (CGMS) continuous glucose monitoring system, (GI) glycemic index, (IAUC) incremental area under the curve, (ISFG) interstitial fluid glucose concentration, (ISIG) input signal of glucose, (PC) personal computer

Keywords: continuous glucose monitoring, data processing, DegifXL software, glycemic index, nutrition

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Introduction

The glycemic index (GI) of a food is defined by the incremental area under the blood glucose curve (IAUC) after the ingestion of 50 grams of carbohydrates in a test food, expressed as a percentage of the IAUC of an equal amount of a reference food (glucose).¹ Conventionally, capillary plasma/blood was used to calculate the IAUC and GI. In 2006, we showed that there was no significant difference between GI determined using the continuous glucose monitoring system (CGMS; Medtronic MiniMed, Northridge, CA) and traditional, more time-consuming conventional methods.² The aims of this forthcoming study were (1) to describe a spreadsheet-based software program created to facilitate the rapid, automated, accurate, and standardized processing of CGM data to measure GI and its variability and (2) to assess the benefits of this new software and methodology.

Material and Methods

Twenty nondiabetic volunteers (6 males and 14 females) aged 24.4 ± 0.71 years (mean \pm SE) provided written informed consent with participation in this study performed in accordance with the Helsinki Declaration and approved by the local ethics committee.

The software program DegifXL was developed using the Microsoft Excel 2000 spreadsheet (Microsoft Corporation, Redmond, WA). Data from CGMS Solutions™ software were processed following a standardized protocol, requiring (1) a team of trained investigators (physicians, educators, dietitians, laboratory workers, information technology support workers); (2) trained subjects with anticipated ability to cooperate with the study protocol; (3) portions of test foods, each containing 50 grams of carbohydrates; (4) hardware—personal computer (PC), CGMS™, and glucometers; and (5) software—MS Excel 2000, CGMS Solutions software, and DegifXL.

Test Period Design

Subjects consumed 50 grams of glucose or four alternative foodstuffs for breakfast and dinner (**Table 1**) beginning in the evening of the first day and continuing testing for the following 7 days, resulting in 15 tests (3 tests per food) performed in each of 20 participants.

At the beginning of the study, the participants were given clearly marked packages containing individual portions of tested foodstuffs. These tested portions were consumed at home according to the protocol. The consumption of all foods was documented in a diary.

Participants were asked to fast for 10 or 4 hours before breakfast and dinner, respectively, and to eat each portion of test food within 5 minutes; simultaneous drinking of 300 milliliters of fluids (water, tea, or coffee) was recommended. During the day (except breakfast, dinner, and respective postprandial 120-minute period), they were free to eat any meal provided that the total daily energy intake remained steady ($\pm 10\%$).

Continuous Glucose Monitoring System Operation

The CGMS sensor was inserted before the first test. The subjects were asked to always enter the event “FOOD” into the monitor before eating the tested food.

Transfer of Data to the DegifXL Spreadsheet

At the end of the test period, CGMS data were downloaded to a PC and exported from CGMS Solutions software 7310 v. 3.0C (Medtronic, MiniMed) to a spreadsheet. CGMS Solutions software stores the values of interstitial fluid glucose concentration (ISFG) in a special directory containing “.mmg” files, which can be transferred from CGMS Solutions software by selecting “File Export” into a separate “.fst” file.

Table 1.
The 8-Day Standard Meal Plan for Five Different Foods Tested through Breakfasts and Dinners^a

Day	1	2	3	4	5	6	7	8
Breakfast		Glucose (2)	Puffed rice squares (4)	Dark chocolate (6)	Apple baby food (8)	Flavored yogurt (10)	Glucose (12)	Puffed rice squares (14)
Dinner	Dark chocolate (1)	Apple baby food (3)	Flavored yogurt (5)	Glucose (7)	Puffed rice squares (9)	Dark chocolate (11)	Apple baby food (13)	Flavored yogurt (15)

^a The number of each meal test is given in parentheses.

Mathematical Principles and Formulas

The IAUC (**Figure 1**) was determined using calculus (integration, as the sum of all 24 trapezoid areas) according to the formula: $IAUC = \sum_{i=1}^{24} S_i$,

$$S_i = \frac{(G_i - G_0) + (G_{i-1} - G_0)}{2} \cdot \Delta t,$$

where G_i is glucose concentration at a particular time, G_0 is starting glucose concentration, and $\Delta t = 5$ minutes. For $G_i < G_0$, $S_i = 0$.

DegifXL offers two ways of defining G_0 . First, G_0 can equal the ISFG value at the beginning of the meal, with the resulting values described as IAUC 1 and GI 1. Second, G_0 can be an average of the five ISFG values preceding (25 minutes) the start of the meal, enabling the calculation of IAUC 2 and GI 2. In order to exclude the potential influence of ISFG outliers, the average G_0 is computed in two steps: (1) the average of five ISFG values is calculated and (2) ISFG values exceeding the empirically defined interval ($\text{avgISFG} \pm 0.3$ mmol/liter) are excluded, and the final G_0 is reaveraged from the resting values.

Next, the subject-related GI for a particular test food is calculated in every individual separately according to the formula:

$$GI = \frac{\text{average IAUC}_{\text{test food}}}{\text{average IAUC}_{\text{glucose}}} \cdot 100[\%]$$

Finally, the group-averaged GI is calculated from all the individuals' calculated GIs.

Data processing in DegifXL

DegifXL consists of four spreadsheets, labeled setup, data, list of probands, and statistics.

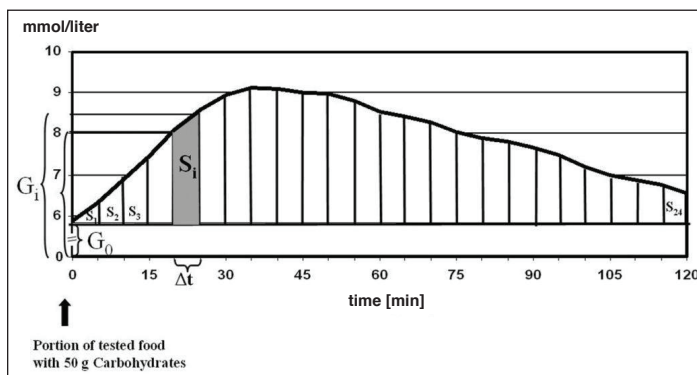


Figure 1. Calculation of the incremental area under the curve. IAUC is calculated as the sum of areas of 24 individual trapezoids. G_0 , glucose concentration before meal intake; G_i , glucose concentration at a particular time; Δt , time interval between estimations (in CGMS, always 5 minutes); S_i , area of the respective trapezoid.

In the setup spreadsheet (**Figure 2**), the user has to fill in the following data:

- The total number of tests planned for one individual into [Planned number of meal tests in one person].
- The exact path to the directory ".fst" into [Directory containing exported data from CGMS Solutions Software (.fst)].
- The limits for ISIG (Input Signal of Glucose registered in the CGMS). If the ISIG is out of range (usually 10–100 nA), DegifXL will exclude the ISFG from further processing.
- The limit for missing ISFG values in one test [Upper limit for No. of invalid values]. If the real number of missing values is higher than the limit set by the user, DegifXL will exclude the test from further processing. Five or less missing ISFG values were accepted in this study.
- The list of tested foods (**Table 1**) and their abbreviations (Marks) into [Order of tested foods as they were consumed during the CGMS measurement].
- Test meal times for morning and evening tests into a separate table [Test meal time]. Tests starting outside this defined period were not processed.
- The empirically defined interval ($\text{avgISFG} \pm 0.3$ mmol/liter) enabling the precise calculation of ISFG 2 and GI 2 into [ISFG glucose tolerance for IAUC 2].
- The number of the test meal in the test schedule must be input into [Order of meal in test]. This function allows calculating average GI for specific foods. If the test meal number is input into the raw [Filter values], the resulting GI will appear in the statistics spreadsheet (**Figure 2**).
- The mark of the morning (M) or evening (E) tests into [Morning/Evening] allows calculation of the GI for either breakfasts or dinners.
- Optional marks into [Other rank] when needed to select meals according to specific criteria (e.g., GI for fresh meals).

The data spreadsheet (**Figure 3**) imports data from an ".fst" file when the user clicks on the button [Import CGMS]. The missing start times must be filled in manually. By clicking on the button [Resulting IAUC] the values of IAUC 1 and IAUC 2 will appear on the screen. Then, data of the next person can be added. The table in the upper part of the data spreadsheet shows the number of successful tests with each food, the number of persons who successfully completed all planned tests (in this

Planned number of meal tests in one person	Directory containing exported data from CGMS Solutions Software (*.fst)	Lower ISIG limit	Upper limit for No of invalid values	ISF glucose tolerance for IAUC2 [mmol/l]	Test meal time	From	Till
15	d:\degif2\	10	5	0.3	Morning	3:00	10:00
					Evening	16:00	22:00

Order of tested foods as they were consumed during the CGMS measurement

Mark	Tested food	Test number
C	Chocolate	1
G	Glucose	2
A	Apple baby food	3
R	Puffed rice squares	4
Y	Yogurt	5
C	Chocolate	6
G	Glucose	7
A	Apple baby food	8
R	Puffed rice squares	9
Y	Yogurt	10
C	Chocolate	11
G	Glucose	12
A	Apple baby food	13
R	Puffed rice squares	14
Y	Yogurt	15
		16
		17
		18
		19
		20
		21
		22
		23
		24
		25
		26
		27
		28
		29
		30

Filter	Order of meal in test	Morning/Evening	Other rank
S e l e c t i o n	1	E	
	1	M	
	1	E	
	1	M	
	1	E	
	2	M	
	2	E	
	2	M	
	2	E	
	2	M	
	3	E	
	3	M	
	3	E	
	3	M	
	3	E	

Meal filter text:

Figure 2. Setup spreadsheet to be completed at the beginning of the analysis. ISIG shows electrical current from the glucose sensor proportional to the glucose concentration.

study, three tests with each food), and the number of people completing one or two tests.

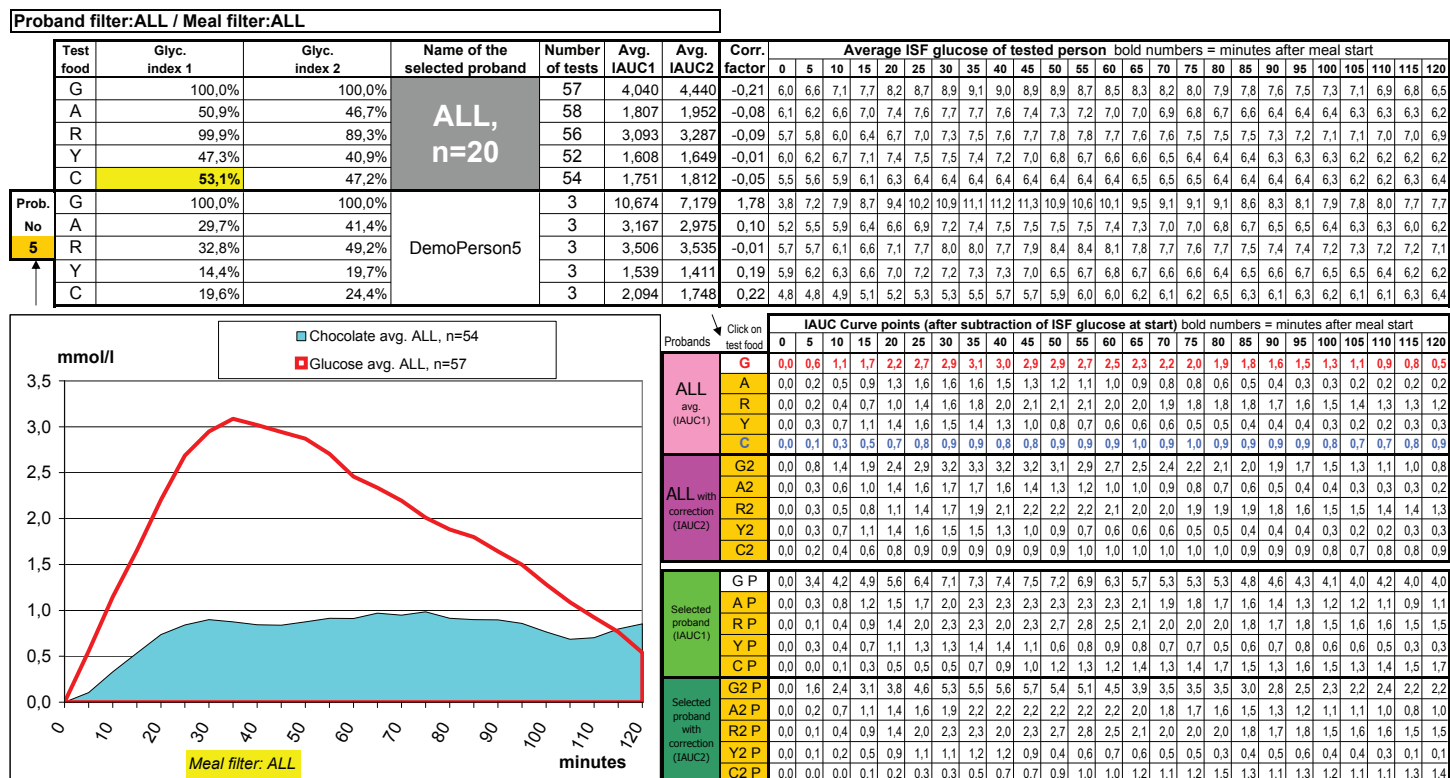
The spreadsheet proband list shows the number of successful tests carried out with particular foods. It also allows performing the selection of probands by entering the particular filter parameter.

After opening the spreadsheet statistics (**Figure 4**), it takes about 30 seconds to recalculate the results according to selection criteria. The following data are shown:

- The group-averaged GI 1 and GI 2, the number of test subjects, the number of successful tests performed with individual foods, and the average IAUC 1 and IAUC 2 for the entire group of all subjects tested.
- The individual subject-related GI 1 and GI 2, the average IAUC 1 and IAUC 2, and the number of successfully processed tests performed with tested foods in one individual selected by clicking on the personal identification number in the yellow field [Prob. No].
- The correction factor [Corr. factor], which is the difference between the G_0 of IAUC 1 and the G_0 of IAUC 2. It is calculated from [Offs] in the data spreadsheet.
- Average ISFG values after the particular food from all 5-minute intervals in the whole group, as well as for a selected individual (top right area of the spreadsheet). IAUCs are calculated from these values.
- The chart showing the IAUC of glucose (the area below the red curve) and the IAUC of the selected

Tested food		Number of tests	Number of selected probands																																	
			3 tests	2 tests	1 test	no test	Σ																													
G	Glucose		14	0	0	14	0	14																												
A	Apple baby food		27	0	13	1	0	14																												
R	Puffed rice squares		14	0	0	14	0	14																												
Y	Yogurt		24	0	10	4	0	14																												
C	Chocolate		24	0	10	4	0	14																												
Total number of tests			103																																	
Import CGMS			Resulting IAUC					Time after meal start																												
Proband	Name	Test No	Test date	Start time	IAUC1	IAUC2	Food	Offs 2	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	Use this symbol		
7	DemoPerson7	1	27.10.2004	18:46	0.37	0.24	C	0.1	6.5	6.5	6.7	6.5	6.5	6.8	6.7	6.2	6.5	7.2	6.9	7.0	6.3	6.2	6.1	5.9	5.8	6.1	6.7	6.7	6.6	6.7	6.9	7.2	7.1	C		
7	DemoPerson7	2	28.10.2004	4:26	4.27	5.01	G	-0.4	4.9	5.3	5.9	6.7	7.2	7.6	8.0	8.2	8.2	8.4	8.3	8.3	8.0	7.5	7.1	6.8	6.8	6.9	6.8	6.3	6.2	6.3	6.2	6.3	6.1			
7	DemoPerson7	3	28.10.2004	18:01	0.48	0.18	A	0.2	6.7	6.5	6.8	6.9	7.0	7.1	6.9	6.9	6.9	6.7	6.9	7.3	7.0	7.0	7.2	7.1	6.8	7.2	7.3	7.0	6.8	6.7	6.8	6.7	6.9	A		
7	DemoPerson7	4	29.10.2004	4:31	3.48	4.07	R	-0.3	5.2	5.2	5.7	5.7	5.7	5.8	6.2	6.5	6.7	6.8	6.9	7.2	7.5	7.8	7.8	7.9	8.4	7.9	7.7	7.5	7.4	7.1	7.3	7.4	7.7			
7	DemoPerson7	5	29.10.2004	18:01	0.53	0.68	Y	-0.1	6.1	6.6	6.3	6.3	6.1	6.9	6.8	6.5	6.4	6.9	6.8	6.5	6.3	6.2	6.7	6.2	6.2	5.9	5.8	5.8	5.8	5.8	5.9	6.2	6.4	Y		
7	DemoPerson7	6	30.10.2004	4:31	0.25	1.04	C	-0.5	5.6	5.6	5.6	5.5	5.7	5.7	5.7	5.8	5.4	5.5	5.3	5.9	5.8	5.8	5.6	5.8	6.1	5.9	5.8	5.6	5.4	5.3	5.3	5.8	6.5			
7	DemoPerson7	7	30.10.2004	18:01	6.52	7.50	G	-0.5	6.0	6.6	7.2	7.9	8.4	8.8	9.4	9.7	10.4	10.7	10.9	11.0	10.7	11.0	10.7	10.3	10.6	10.2	9.7	9.5	8.6	8.1	7.8	7.4	7.2	G		
7	DemoPerson7	8	31.10.2004	4:31	2.54	3.52	A	-0.5	6.1	6.4	6.7	7.2	7.6	7.8	7.9	8.1	8.2	8.2	7.8	7.7	7.7	7.7	7.6	7.4	7.3	7.2	7.1	7.0	7.0	6.9	7.0	6.7				
7	DemoPerson7	9	31.10.2004	18:31	1.98	1.53	R	0.3	5.7	5.7	6.0	6.0	5.8	5.9	6.0	6.2	6.7	6.7	6.8	6.6	7.5	7.9	7.7	7.7	7.6	7.9	7.0	7.0	6.6	6.7	5.8	6.2	7.5	R		
7	DemoPerson7	10	1.11.2004	4:31	2.63	2.83	Y	-0.1	5.3	5.9	6.3	6.7	7.0	7.3	7.5	7.5	7.6	7.2	7.0	6.9	6.9	6.5	6.2	6.0	6.0	6.5	6.6	6.5	6.3	6.2	6.2	6.2	6.3			
7	DemoPerson7	11	1.11.2004	18:01	3.19	4.60	C	-0.7	5.2	5.4	5.4	5.7	6.2	6.5	6.6	6.4	6.9	6.8	7.4	7.6	7.6	7.4	6.9	6.9	6.8	6.7	7.3	7.4	7.4	7.2	7.0	7.1	7.7	C		
7	DemoPerson7	12	2.11.2004	4:31	6.99	7.25	G	-0.1	5.1	5.8	6.6	7.5	7.9	8.3	9.0	9.3	9.3	9.5	9.9	9.3	9.8	9.8	10.2	10.0	9.7	9.3	9.1	8.8	8.5	8.0	7.3	7.4	6.9			
7	DemoPerson7	13	2.11.2004	18:01	0.53	0.15	A	0.3	5.8	6.0	6.3	6.5	6.5	6.4	6.1	6.1	6.1	6.3	6.2	6.1	6.2	6.1	6.1	6.2	5.9	5.9	5.8	5.2	4.9	4.7	4.8	4.9	5.0	A		
7	DemoPerson7	14	3.11.2004	4:31	2.72	3.11	R	-0.2	4.8	4.8	5.3	5.5	5.8	5.9	6.1	6.2	6.8	6.9	6.5	6.7	6.7	6.6	6.9	6.8	6.5	6.1	5.9	5.7	6.1	6.2	6.2	6.2	6.1			
7	DemoPerson7	15	3.11.2004	18:01	0.28	0.43	Y	-0.2	5.6	6.1	5.9	6.1	5.7	6.2	5.7	5.4	5.9	5.3	5.4	6.0	5.5	5.8	5.3	5.3	5.4	5.1	5.4	5.9	5.6	5.3	5.0	5.3	4.2	Y		
8	DemoPerson8	1	27.10.2004	18:37	0.75	1.21	C	-0.2	4.6	4.6	4.7	4.7	4.8	4.7	4.8	4.8	4.6	4.4	4.7	4.7	4.8	4.7	5.2	5.9	5.9	5.7	5.4	5.3	5.1	4.8	4.8	4.9	5.9	C		
8	DemoPerson8	2	28.10.2004	5:12	3.29	3.29	G	0	6.3	5.4	5.6	5.7	6.5	7.4	7.9	7.4	7.7	7.9	7.9	7.8	7.8	7.8	8.0	8.5	9.4	10.8	10.5	9.1	8.9	8.3	7.7	7.6	7.5			
8	DemoPerson8	3	28.10.2004	18:32	3.05	3.05	A	0	4.6	4.8	5.3	5.6	6.1	6.5	6.6	7.0	7.0	6.8	6.4	6.3	6.1	6.1	6.2	6.0	6.1	6.1	6.2	6.3	6.4	6.1	6.1	5.7	5.9	A		
8	DemoPerson8	4	29.10.2004	5:27	2.35	1.49	R	0.6	4.6	4.6	4.2	3.7	3.7	3.7	3.7	5.9	6.4	6.7	6.7	6.7	6.9	6.9	7.2	6.8	6.4	6.2	5.7	5.7	5.4	5.4	5.8	5.5	4.9			
8	DemoPerson8	5	29.10.2004	18:27				0.9	6.2	7.3	6.8	6.7	6.7	7.4	8.0	7.8	6.9	6.9	6.4	5.9	5.6	5.7	5.2	5.1	4.9	5.1	5.1	4.8	4.8	4.8	4.8	4.8	4.8			
8	DemoPerson8	6	30.10.2004	5:32				0.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0			
8	DemoPerson8	7	30.10.2004	18:32	8.89	9.12	G	-0.1	5.6	5.9	6.5	7.3	8.0	9.0	10.0	10.6	10.4	10.8	11.5	11.9	11.7	12.0	12.4	12.0	12.0	11.5	11.5	11.1	10.5	9.9	9.4	8.4	7.9	G		
8	DemoPerson8	8	31.10.2004	5:17	2.53	2.22	A	0.2	5.0	5.6	6.2	6.5	6.9	7.0	7.2	7.4	7.2	6.9	6.8	6.7	6.5	6.3	6.2	6.1	6.1	6.0	5.8	5.6	5.4	5.4	5.5	5.8	5.6			
8	DemoPerson8	9	31.10.2004	18:32	7.55	7.94	R	-0.2	5.5	5.5	6.3	6.6	7.5	8.3	9.0	9.0	9.2	9.4	9.9	9.8	9.9	10.0	10.5	10.6	10.4	10.3	10.5	10.5	10.4	10.9	10.7	10.0	9.2	R		
8	DemoPerson8	10	1.11.2004	5:12	2.31	3.09	Y	-0.4	4.9	4.9	5.2	5.8	6.5	7.0	7.2	7.3	7.3	6.6	6.2	6.1	6.0	6.1	5.9	5.9	5.9	5.9	5.8	5.8	5.5	5.5	5.6	5.9	5.9			
8	DemoPerson8	11	1.11.2004	18:27	2.64	2.84	C	-0.1	5.3	5.6	6.0	6.1	6.4	6.6	6.1	6.4	6.7	6.8	7.0	6.8	6.9	6.9	6.9	7.0	6.8	6.8	7.0	7.3	7.2	7.0	6.5	6.3	6.3	C		
8	DemoPerson8	12	2.11.2004	5:12	7.80	8.19	G	-0.2	5.0	5.7	6.7	7.2	7.9	8.7	9.3	10.1	10.3	10.5	10.7	10.7	10.8	10.9	11.0	10.8	9.9	10.4	10.0	9.2	8.3	7.3	6.2	5.9	5.1			
8	DemoPerson8	13	2.11.2004	18:32	3.75	4.30	A	-0.3	5.1	5.7	6.6	7.2	7.7	7.7	8.2	8.5	8.5	8.2	8.0	7.9	7.6	7.5	7.4	7.2	6.7	6.7	6.6	6.2	5.9	5.6	5.4	5.3	5.2	A		
8	DemoPerson8	14	3.11.2004	5:12	4.45	4.22	R	0.1	4.4	5.1	6.0	7.0	7.4	7.2	8.3	8.3	7.3	7.9	8.7	8.3	7.4	7.0	6.3	5.7	5.8	5.7	5.9	5.9	6.0	5.3	5.4	6.1	5.6			
8	DemoPerson8	15	3.11.2004	18:17	3.78	3.32	Y	0.3	4.1	4.1	5.8	5.4	5.9	6.6	7.6	8.3	7.2	7.1	6.4	6.2	7.2	7.7	7.8	7.8	6.7	5.7	4.8	4.4	4.1	4.1	4.1	4.1	5.3	Y		

Figure 3. Data spreadsheet, which is generated by clicking on [Import CGMS]. Offs: the difference between G_0 for IAUC 1 and G_0 for IAUC 2. G_0 for IAUC 2 is calculated as the mean of five glucose concentration measurements prior to the meal.



food (the blue area); numerical values of the glucose concentration increments from the IAUC curve points (after subtraction of G_0 at start) appear in colored boxes on the right part of the sheet. Each curve begins when the meal starts and ends 120 minutes later. G_0 , the type of food, and the type of GI (group- or subject-related GI) are defined by clicking on the corresponding button in the [Test food] column. The actual selection is always shown in the right upper corner of the chart, and the field containing the GI appears in yellow.

- Switching from one spreadsheet to another and printing are possible at any time. The user may immediately access the group- and individual subject-related GI, the GI from morning and evening tests, from men and women, and so on.

Assessment of DegifXL

The efficiency of using the CGMS/DegifXL software was considered to be a percentage of successfully processed tests from the total number of tests in 20 volunteers. Next, extreme values of GI (over 500%) were excluded and the final statistical analysis was performed using the program SPSS v. 14.0 (SPSS Inc., Chicago, IL). The time needed to determine the GI using DegifXL was compared with the conventional method.²

Results

The GI values are shown in **Table 2**. No significant difference neither between replicate measurements in tests 1, 2, and 3 nor breakfast and dinner tests can be seen.

Using the CGMS/DegifXL system, there were 277 successful tests (92.3%) from the 300 tests performed in the group of 20 healthy volunteers. For each of five tested foods, 60 tests were performed. The number of successfully processed tests for the individual foods ranged from 52 (86.7%) to 58 (96.7%). The test failures were tester related ($n = 8$) or CGMS related ($n = 15$). The time-saving effect of using the CGMS/DegifXL system is shown in **Table 3**. Processing data from the 20 volunteers using DegifXL was about 12 times faster than using conventional methods.

There were no technical problems while obtaining either group-averaged or subject-related GIs for five different foods in the 20 test subjects using DegifXL. The DegifXL demo version can be obtained from the authors.

Discussion

In 1973, Otto and colleagues³ introduced the concept of GI; other groups demonstrated how dietary carbohydrates affect blood glucose levels^{1,4–6} and applied the GI in clinical practice, emphasizing its relevance for glycemic control in persons with diabetes.^{7–10} In 1998, the World Health Organization and the Food and Agriculture Organization recommended including GI values in nutrition tables and promoting low GI foods as a part of a healthy diet.^{11,12} In the present study, the terms “group-averaged GI” and “subject-related GI” were introduced. Published GI tables¹³ show group-averaged GIs only, and the large variability in the GIs is ascribed to various factors.^{14–17} However, the determination of individual subject-related GIs has improved our understanding of metabolic processes dealing with carbohydrates.^{18–22} It is also a useful concept in relation to glycogen storage and release in the course of physical exercise^{23–25} and to occupational activities.²⁶ The software DegifXL is particularly helpful for easy determination of subject-related GIs, which may be compared quickly with the respective group-related GI.

Conventional methods for calculating GI have been widely used.^{27,28} However, such methods are time-consuming and still not fully standardized. In our study, the glucometer Advance system (Hypoguard, Woodbridge, UK)²⁹ was used to calibrate the CGMS. The CGMS sensor was kept inserted for 8 days and no adverse events appeared.^{30,31} Because the CGMS stores ISFG values, it is not necessary to record the exact timing of finger pricks. All ISFG measurements are performed in the same way, and the same algorithm is used for data processing. DegifXL calculates the initial baseline glucose in two different ways, using either the zero time value or the average of five glucose readings 25 minutes prior to mealtime. Further trials are necessary to determine whether the optional IAUC 2 calculation by DegifXL would give better results.

In this trial, GIs were investigated in healthy volunteers. The preliminary results of other studies show that the values of respective GIs in persons with type 1 and type 2 diabetes are not statistically different.^{32–36} DegifXL enables one to also perform detailed data processing in persons with diabetes and/or to determine the GI values for breakfast and for dinner times, for men and women, and so on. Consumption of high glycemic index food does not seem to result in worsening of glycemic control in type 1 diabetes. Further studies are in progress to

Table 2.
Glycemic Index in Particular Tests (1–3) and Times (Breakfast and Dinner) Obtained by DEGIF XL and, after Exclusion of Extreme Values (GI >500%), Analyzed by SPSS v. 14.0 (Means \pm SE)

Meal	GI (%) (mean \pm SE)						Significance of difference (p)	
	Test 1	Test 2	Test 3	Breakfast	Dinner	All	Test 1 vs 2 vs 3 (ANOVA)	Breakfast vs dinner (paired t test)
Dark chocolate	43.7 \pm 19.6 $n = 14$	52.1 \pm 13.3 $n = 17$	50.9 \pm 6.7 $n = 19$	52.1 \pm 13.3 $n = 17$	46.9 \pm 7.5 $n = 20$	50.6 \pm 7.4 $n = 20$	0.898	0.615
Apple baby food	62.9 \pm 12.9 $n = 17$	71.9 \pm 12.8 $n = 19$	42.4 \pm 9.9 $n = 18$	71.9 \pm 12.8 $n = 19$	50.5 \pm 7.1 $n = 19$	60.5 \pm 7.2 $n = 20$	0.206	0.353
Rice squares	98.6 \pm 23.0 $n = 16$	129.3 \pm 24.9 $n = 19$	68.9 \pm 10.2 $n = 17$	81.3 \pm 9.8 $n = 19$	129.3 \pm 24.9 $n = 19$	100.3 \pm 9.1 $n = 20$	0.124	0.174
Flavored yogurt	68.7 \pm 24.5 $n = 16$	66.2 \pm 13.0 $n = 17$	33.4 \pm 7.9 $n = 15$	66.2 \pm 13.0 $n = 17$	56.1 \pm 14.8 $n = 20$	56.2 \pm 9.0 $n = 20$	0.277	0.787

Table 3.
Mean Duration of Data Processing to Determine the GI Using CGMS Solutions Software/DegifXL Compared to Nine-Point Meal Tests Performed with Glucometer Advance System (GAS) for Five Different Foods

Procedure	No. of tests	No. of persons	Duration of procedure (minutes)	
			CGMS	GAS
Checking CGMS protocol	15	1	1	-
Checking GAS protocol	15	1	-	30
Data transfer from CGMS into the .mmg file using Solutions software	15	1	3	-
Input of data from protocols into MS Excel file	15	1	-	60
Data export from CGMS .mmg file to .fst file	15	1	1	-
Preparing calculation in MS Excel	15	1	-	5
Data import from .fst file into DegifXL and calculation of GIs	15	1	3	-
Construction of diagram for one person	15	1	-	5
Total (1 person)	15	1	8	100
Total (20 persons)	300	20	160	2000

verify the procedure with type 1 and type 2 diabetes and to validate that GI interstitial fluid glucose is the same as the manual method using plasma. In addition, attempts have been made to determine the GI at lunch and at afternoon snack times.³⁷

For an approximate comparison and demonstration of differences between results obtained in individual centers using similar methods, it should be mentioned that in another study the GI was assessed to be 29% for chocolate, 34% for apples, 47% for rice, 89% for cornflakes, and 27% for yogurt.¹³

Clinically, it is important to evaluate the glycemic profiles of individuals with diabetes in response to a given food in combination with a particular therapy, e.g., the

glycemic response to a mixed meal or to a complex food such as pizza. Currently, we are refining DegifXL so that it can be used for these applications.

Using DegifXL is quite simple. Perspectively, an educated person might be able to determine his/her subject-related GIs at home. However, the routine determination of a group-related GI should be carried out in a specialized center staffed by qualified professionals who have been trained properly.³⁸

To summarize, the strength of this new protocol is that it automates GI calculation. Next, DegifXL calculates the mean subject-related GI (using GIs from one to three tests) and the group-averaged GI for all study subjects. In trained individuals, the former may be performed

at home, the latter under supervision in a specialized center. Some statistics are directly available; additional statistical software allows determining the extent of variability between tests for the same food in the same subject and the variability in GI for a given food. Data processing using DegifXL is about 12 times faster than by conventional methods. This software will be developed further in response to future challenges.

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