GH-Method: Math-Physical Medicine
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An Investigation of Continuous Glucose Monitor Based Postprandial Plasma Glucose Waves and Results Using GH-Method: Math-Physical Medicine (No. 304)

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Abstract

This article is a study of postprandial plasma glucose (PPG) waveforms and results over a period of 822 days from 5/5/2018–8/4/2020. It consists of 29,592 continuous glucose monitor (CGM) sensor readings and 2,466 finger-piercing measurements for a total of 32,058 PPG values. The research methodology utilizes the author developed GH-method: math-physical medicine (MPM) which has been applied for the past decade. Listed below are the summarized key data in the order of CGM-15 min PPG, finger PPG, carbs/sugar, and post-meal walking steps:

Breakfast: 134 mg/dL, 115 mg/dL, 9.8 g, 4,433 steps
Lunch: 138 mg/dL, 116 mg/dL, 17.1 g, 3,975 steps
Dinner: 128 mg/dL, 110 mg/dL, 14.7 g, 4,478 steps
Daily: 133 mg/dL, 113.8 mg/dL, 13.9 g, 4,294 steps

Applying his PPG prediction method, the calculation of predicted PPG using his formula-based approach on the status of fasting plasma glucose (FPG), carbs/sugar intake amount, and post-meal walking steps are shown:

*Predicted finger PPG = 0.966 * finger FPG + (carbs/sugar in grams * 2) - (post-meal walking steps in thousand * 5)*
*Predicted PPG = 0.966 * 111.2 + (13.9 * 2) - ((4294/1000) * 5)*
= 107.5 + 27.7 - 21.5
= 113.7 mg/dL

The comparison of this formula-based finger PPG prediction of 113.7 mg/dL with the actual measured finger PPG of 113.8 mg/dL has shown ~100% of the PPG prediction accuracy. The following 5 PPG values are arranged by their average glucose levels from high to low:

60 min: 141.96 mg/dL; daily average: 133.39 mg/dL; 120 min: 130.42 mg/dL; 180 min: 129.08 mg/dL; 0 min: 127.87 mg/dL

In summary, there are four conclusive statements:

1) The author's lifestyle of having a heavier lunch results with the highest PPG value compared

to the other meals of the day.
2) The peak of PPG occurs around 60 min after the first bite of his meal, not the traditional standard of 2 h after.
3) The differences between the higher CGM PPG and the lower finger PPG are between 13–17%. However, with his ongoing lifestyle management improvements, these two PPG values are converging together.
4) His formula-based finger PPG prediction model can provide a near 100% prediction accuracy.

Keywords: plasma glucose, diabetes, glucose, nutrition, metabolism

Abbreviations: PPG: postprandial plasma glucose; CGM: continuous glucose monitor; MPM: math-physical medicine; FPG: fasting plasma glucose; HbA1C: hemoglobin A1C; T2D: type 2 diabetes

Introduction

This article is a study of postprandial plasma glucose (PPG) waveforms and results over a period of 822 days from 5/5/2018–8/4/2020. It consists of 29,592 continuous glucose monitor (CGM) sensor readings and 2,466 finger-piercing measurements for a total of 32,058 PPG values. The research methodology utilizes the author developed GH-method: math-physical medicine (MPM) which has been applied for the past decade [1].

Methods

GH-method: math-physical medicine methodology

The description below explains the MPM research methodology developed by the author utilized in his biomedical research.

Any system, whether medical, political, economic, engineering, biological, chemical, and even psychological have causes or triggers (inputs) and consequences (outputs). There are definitely some existing connections between inputs and outputs that can be either simple or complicated. The inputs and outputs of any type of system, including biomedical system, can be observed visually, or measured by certain instruments. These physically observed phenomena, including features, images, incidents, or numbers are merely the partial "physical expression" of these underneath system structure. This system structure includes human organs for a biomedical system, the human brain for a neurological or mental system, or steel plate for structural or mechanical engineering system.

Once we have collected these readings of the physical phenomena (external expression, similar to a behavior, symptom, or response), through either incident, image, or data, we should be able to organize or categorize them in a logical manner. When we check or analyze these partial physical phenomena outputs and cannot figure out why they act or behave in certain way due to internal causes, reasons, or stressors, we can try to develop some guesses or formulate some reasonable hypotheses based on some available basic principles, theories, or concepts from physics. At this point, we just cannot pull out an existing equation from a physics textbook and insert these input variables in to conduct a "plug and play" game. An equation is an expression of a concept or a theory, which is usually associated with some existing conditions, either initial or boundary; however, a biomedical system usually has different kind of conditions from other systems.

After understanding the meaning of observed physical phenomena, the next step is to prove the hypothesis, guess, or interpretation of the phenomenon being correct or incorrect. At this stage, a solid understanding of mathematics

becomes extremely useful to develop a meaningful model which could represent or interpret these observed physical phenomena and created hypothesis. In addition, some engineering modeling techniques, such as finite element method and computer science tools, including software, artificial intelligence (AI), and big data analytics can offer great assistance on verification of analysis results from these mathematical operations.

If the mathematical results cannot support the created hypothesis, then a new hypothesis needs to be formulated. When this new hypothesis is proven to be correct, then we can extend or convert this hypothesis into a useful mathematical equation or into a simpler arithmetical formula for others to adopt this easier way of thinking and understanding of the results. In the final stage, the derived mathematical equation or arithmetical formula can then be used to "predict" future outcomes of the selected system based on other different sets of inputs [2].

Diabetes research

The author has been a severe type 2 diabetes (T2D) patient since 1995. He has developed many serious complications and finally, in 2010, they became life-threatening. Therefore, he has spent the next 10 years to self-study and research diabetes, metabolism, and endocrinology, in order to save his own life.

He spent his first 4 years, from 2010–2013, to self-study 6 chronic diseases, *i.e.*, obesity, diabetes, hypertension, hyperlipidemia, cardiovascular diseases, stroke, as well as food nutrition. Food is probably the most important and complicated input element to influence these chronic diseases. After his first 4 years of self-learning, he then spent the entire year of 2014 to develop a complex model of metabolism. This mathematical model contains 4 biomarkers of medical conditions (weight, glucose, blood pressure, and lipids) along with 6 lifestyle details (food portion and nutritional balance, water intake, exercise, sleep amount and quality, stress reduction, and daily life routines regularity). He applied the concept of topology and the approximation engineering modeling technique of finite element method to develop this metabolism mathematical model which became the cornerstone of his future research work.

Starting from 2015, he spent 3 consecutive years, from 2015–2017, to discover the characteristics and behaviors of this complex "wild beast" of glucose. His major objective is to truly understand the "inner characteristics" of the glucose, not just using medication's chemical power to control its "external biological symptoms". His research work is similar to a horseman trying to tame a horse by understanding its temperament first, not just giving a tranquilizer to calm it down. As a result, during this period of 3 years, he has developed 4 prediction models, which include weight, PPG, fasting plasma glucose (FPG), and hemoglobin A1c (HbA1C) with very high prediction accuracy (95–99%) to reach to his purpose of understanding glucoses [3, 4].

The author estimated and proved that PPG contributes approximately 75–80% towards HbA1C formation. Therefore, he tried to unravel the mystery of PPG first. Through his diabetes research, he has identified at least 19 influential factors associated with PPG formation. Among those influential factors, diet (carbs/sugar intake amount) would provide ~38% and exercise (post-meal walking) would contribute ~41%. Combining these two primary influential factors, it gives ~80% of the PPG formation. Among the rest of the 17 secondary factors, a high weather temperature contributes ~5%, whereas stress and illness only make noticeable contributions when they occur.

For most T2D patients who take medications, its biochemical effect would become the most significant influential factor. However, as we know, medication cannot cure diabetes and only control its symptoms. Therefore, the author decided to focus on controlling diabetes at the most fundamental level by investigating its root cause. Previously, he has taken high doses of three prescribed diabetes medications for 18 years since 1997; however, in 2013, he started to reduce the number of prescriptions and dosages of his daily medications. By 12/8/2015, he finally ceased taking any diabetes medications.

From 2016–2017, he discovered a solid statistical connection between his FPG and his weight (> 90% of correlation coefficient). In addition, similar to his PPG research, he also recognized that there are about 5 influential factors of FPG formation with weight alone contributing > 85% and cold weather temperature influencing ~5%.

Since July 2019, he also launched a special investigation on the degree of damage to his pancreatic beta cells. During the past 12 months of research work, he noticed that both of his FPG and PPG have been decreased in the past 6–8 years at an annual rate of 2.2–3.2%. In other words, his pancreatic beta cells have been self-regenerating or self-repairing about 13–26% over these 6–8 years. He then thought about FPG as being a good indicator on how healthy his pancreatic beta cells are since there are no food intake and exercise while sleeping. During the last 5 years, his body weight has been maintained around 172 lbs. Besides, his body has been medication-free over the past 5 years as well. It makes sense that FPG carries a significant and clear message about his health status of pancreatic beta cells; therefore, it can be served as the baseline of his overall glucose predications.

The detailed explanation of his glucose research work is provided because this particular study is based on "glucoses".

Glucose data collection

During this investigation period, he utilizes the Freestyle Libre CGM on his upper arm to collect glucose values at 15 min time intervals. Therefore, the collection rate is comprised of 96 glucose data and 36 PPG data per day. The PPG data of each meal contain 12 data points, from 0 min throughout 180 min with 15 min time intervals. While no device is free of defects, the existing glucose measuring devices, both finger-piercing testing strip and CGM sensor have their respective inherent reliability issues.

At the same time, he has kept a complete record of his carbs/sugar intake amount in grams and post-meal walking steps associated with each of his 2,450 meals over these 822 days.

Results

Figure 1 has a data table on its top diagram which includes all his collected and calculated background data of this study. Its bottom diagram is a line chart that contains his 4 PPG curves of breakfast, lunch, dinner, and daily PPG. It is obvious that his lunch PPG waveform is the highest, next is breakfast, and then dinner is the lowest among these 3 waveforms. His eating times starting with breakfast is at 07:00, lunch at 12:00, and dinner at 18:00. His eating patterns include good-protein and high-quality breakfast, then lunch with the largest volume with a variety of meal contents, and a simple and smaller volume for dinner (due to his weight control). Although he has strong knowledge about food nutrition and diet limitations for diabetes, it is inevitable to consume more amount of carbohydrates and sugar during lunch, which is his largest meal of the day. It should be mentioned that his post-meal walking steps have been consistent around 4,000 steps after each meal for the past 6 years [5].

This line chart depicts 4 curves (*i.e.*, waveforms) of his synthesized PPG on a meal-time scale of 3 h from the first bite at 0–180 min. This figure is generated by averaging all the 36 measured glucoses for each meal per day over these 822 days. As a result, the author developed his data analysis software to use the average glucoses of these 36 data within 3 meal h to be the patient's average PPG.

Listed below are the summarized key data in the order of CGM-15 min PPG, finger PPG, carbs/sugar, and post-meal walking steps (Figure 1):

Breakfast: 134 mg/dL, 115 mg/dL, 9.8 g, 4,433 steps
Lunch: 138 mg/dL, 116 mg/dL, 17.1 g, 3,975 steps
Dinner: 128 mg/dL, 110 mg/dL, 14.7 g, 4,478 steps
Daily: 133 mg/dL, 113.8 mg/dL, 13.9 g, 4,294 steps

Meals	First-bite	15-min	30-min	45-min	60-min	75-min	90-min	105-min	120-min	135-min	150-min	165-min	180-min	Avg PPG
Breakfast	120	125	134	142	144	141	137	134	133	132	132	132	131	134
Lunch	134	137	143	147	147	145	142	139	135	133	131	131	130	138
Dinner	128	130	134	135	134	130	127	124	123	123	123	125	124	128
Average-Math	128	131	137	141	142	139	135	133	130	130	129	129	129	133.14
Average-S/W	127	130	137	141	142	139	136	133	130	130	129	129	129	133.18
Meals	Carbs/Sugar	Walking	Meals #	Finger PPG	peak-start	FPG-Finger	FPG-CGM	Baseline (96.6%)	+ Carbs (*2)	- Walking (*5)	PPG-Formula	PPG predict %		
Breakfast	9.8	4433	818	115.2	24									
Lunch	17.1	3975	821	115.9	13									
Dinner	14.7	4478	811	110.2	7									
Average	13.9	4294	2450	113.8	14	111.2	111.3	107.5	27.7	21.5	113.7	100.0%		

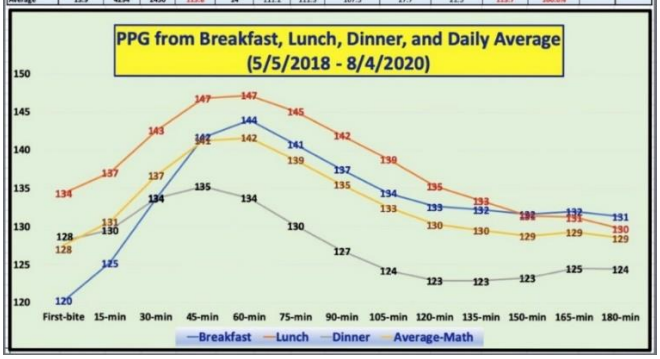

Figure 1: Data table and line chart of synthesized PPG waveforms of breakfast, lunch, dinner, and daily using CGM-15 min glucoses over 822 days (5/5/2018–8/4/2020).

Applying his PPG prediction method [6], the calculation of predicted PPG using his formula-based approach on the status of FPG, carbs/sugar intake amount, and post-meal walking steps are shown:

Predicted Finger PPG = 0.966 * finger FPG + (carbs/sugar in grams * 2) - (post-meal walking steps in thousand * 5)

Predicted PPG = 0.966 * 111.2 + (13.9 * 2) - ((4294/1000) * 5)

= 107.5 + 27.7 - 21.5

= 113.7 mg/dL

In figure 1, the data table indicates his PPG rising due to his average carbs/sugar intake of 13.9 g which would generate ~27.7 mg/dL PPG amount. Around 45 min after his first bite of meal, he starts to do his routine post-meal walking exercise at 4,294 steps which would reduce to ~21.5 mg/dL PPG. Therefore, the net gain of his PPG from his carbs/sugar intake and post-meal exercise would be ~6.2 mg/dL.

The comparison of this formula-based finger PPG prediction of 113.7 mg/dL with the actual measured finger PPG of 113.8 mg/dL has shown ~100% of PPG prediction accuracy. Even if he uses 100% of finger FPG as his baseline PPG, he still can obtain a predicted PPG of 117.5 mg/dL with ~97% of prediction accuracy.

The figure shows the comparison among 5 PPG waveforms over the 822 days at the first bite at 0 min, 60 min, 120 min, 180 min, and daily average PPG (Figure 2). The following 5 PPG values are arranged by their average glucose levels from high to low: 60 min: 141.96 mg/ dL; daily average: 133.39 mg/dL; 120 min: 130.42 mg/dL; 180 min: 129.08 mg/dL; 0 min: 127.87 mg/dL.

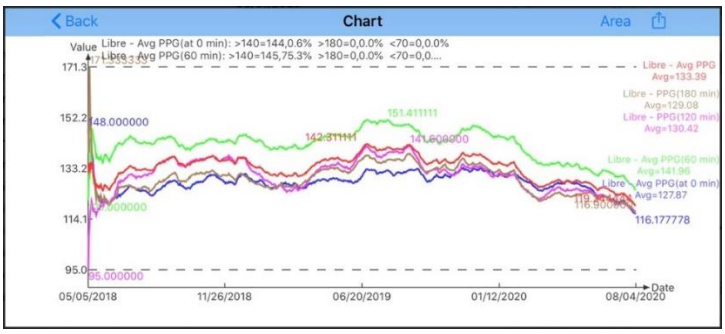

Figure 2: 90-days moving average PPG waveforms at 0 min, 60 min, 120 min, 180 min, and daily average using CGM-15 min glucoses over 822 days (5/5/2018–8/4/2020).

The PPG wave moves from its lowest point at 0 min then moves upward to reach its peak at 60 min, and later moves downward to its lowest positions between 120 min and 180 min. The standard advice given to diabetes patients in measuring their PPG at 2 h after the first bite of their meal has no valid reason for it. At 120 min, it essentially catches their lowest PPG, not the highest PPG at 60 min.

The figure demonstrates a comparison between CGM-15 min PPG and finger PPG within two different periods (Figure 3). The top diagram reflects a longer period of 2+ years, from 5/5/2018–8/4/2020, with CGM PPG of 133 mg/dL and finger PPG of 114 mg/dL. The bottom diagram reveals a shorter period of 6+ months, from 1/19/2020–8/4/2020, with CGM PPG of 124 mg/dL and finger PPG of 110 mg/dL. These two diagrams prove that his PPG are improving based on both finger PPG and CGM-15 min PPG. Furthermore, the CGM PPG is 17% higher than finger PPG during the longer period, while the CGM PPG is only 13% higher than finger PPG during the shorter period. This means that these two different measurements of PPG values are converging together.

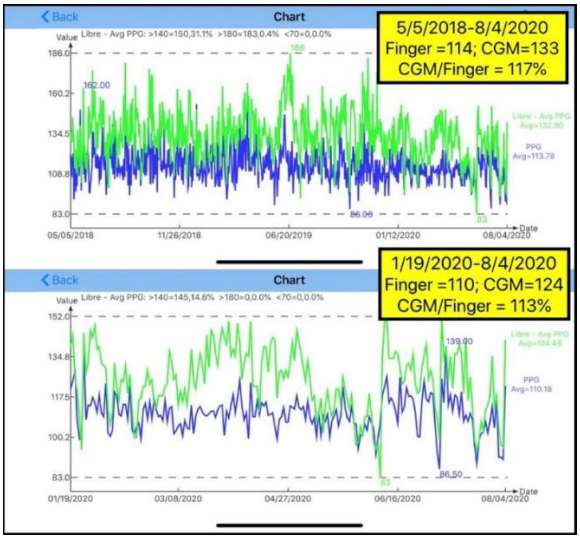

Figure 3: Daily average PPG waveforms of both finger and CGM-15 min for two periods - longer period: 5/5/2018–8/4/2020 and shorter period: 1/19/2020–8/4/2020.

Conclusion

In summary, there are four conclusive statements:

1) The author's lifestyle of having a heavier lunch results with the highest PPG value compared to the other meals of the day.
2) The peak of PPG occurs around 60 min after the first bite of his meal, not the traditional standard of 2 h after.
3) The differences between the higher CGM PPG and the lower finger PPG are between 13–17%. However, with his ongoing lifestyle management improvements, these two PPG values are converging together.
4) His formula-based finger PPG prediction model can provide a near 100% prediction accuracy.

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