High accuracy of predicted postprandial plasma glucose using two coefficients of GH.f-modulus and GH.p-modulus from linear elastic glucose behavior theory based on GH-Method: math-physical medicine, Part 5 (No. 357)

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Abstract

This article is Part 5 of the author's linear elastic glucose behavior study, which focuses on the predicted postprandial plasma glucose (PPG). This study is the combination and continuation of his previous four studies, Parts 1, 2, 3, and 4, on linear elastic glucose behaviors

Listed below are his two recently developed linear elastic glucose equations with two defined coefficients of GH-modulus and his third equation for the predicted PPG from combining these two equations together:
*(1) FPG = GH.f-modulus * Weight*

Where Weight is the input component (similar to stress) and FPG is the output component (similar to strain).

*(2) Incremental PPG= GH.p-modulus * Carbs&sugar*

Where
Incremental PPG= Predicted PPG - (0.97 * FPG)+ (post-meal walking k-steps * 5)

When he combines the above two linear elastic equations into one, he has the following new PPG prediction equation:

*(3) Predicted PPG= (0.97 * GH.f-modulus * Weight) +(GH.p-modulus * Carbs&sugar) - (post-meal walking k-steps * 5)*

The three equations from above were inspired by his prior knowledge in the theory of elasticity in strengths of engineering materials which has the following engineering equation developed in 1807 by a British scientist, Thomas Young:

*Stress = Young's modulus * Strain*

Young's modulus and the two biomedical coefficients (GH.f-modulus and GH.p-modulus) are reciprocal to each other.

The main objective of this study is to offer numerical proof for the PPG prediction accuracy using the above-mentioned equation (3) and based on his own health data collected from 7/1/2015 to 10/31/2020.

Listed below are the annual values of the GH.f-modulus, GH.p-modulus, PPG prediction % for the author's case which reflect his severity levels of both obesity and diabetes, and PPG prediction accuracy %:

Y2015: (0.71, 1.6,97%)
Y2016: (0.68, 1.8,99%)
Y2017: (0.69, 1.6, 100%)

Y2018: (0.66, 1.9, 100%)
Y2019: (0.66, 1.8,99%)
Y2020: (0.59, 2.4, 103%)

Average: (0.67, 1.9, 100%)

The author applied his linear elastic glucose theory of both FPG and PPG behaviors on the predicted PPG value with high accuracy in order to help other diabetes patients. The five major internal organs involved in glucose production are the brain, stomach, intestines, liver, and pancreas along with three major inter-organ systems including blood, nerves, and hormones. This study has further proved via a quantitative analysis that PPG level has a close connection with FPG, weight (food quantity), carb/sugar intake (food quality), and exercise.

This article represents the author's special interest in using math-physical and engineering modeling methodologies to investigate various biomedical problems.The methodology and approach are the results of his specific academic background and various professional experiences prior to the start of his medical research work in 2010. Therefore, he has attempted to link his newly acquired biomedical knowledge over the past decade with his previously acquired knowledge of mathematics, physics, computer science, and engineering for over 40 years.

The human body is the most complex system he has dealt with, which includes aerospace, navy defense, nuclear power, computers, and semiconductors. By applying his previous acquired knowledge to his newly found interest of medicine, he can discover many hidden facts or truths inside the biomedical systems. Many basic concepts, theoretical frame of thoughts, and practical modeling techniques from his fundamental disciplines in the past can be applied to his medical research endeavor.After all, science is based on theory via creation and proof via evidence, and as long as we can discover hidden truths, it does not matter which method we use and which option we take. This is the foundation of the GH-Method: math-physics medicine.

The author has spent four decades as a practical engineer and understands the importance of basic concepts, sophisticated theories, and practical equations which serve as the necessary background of all kinds of applications. As a result, he spent his time and energy to investigate glucose related subjects using variety of methods he studied in the past, including this particular interesting stress-strain approach.On the other hand, he also realizes the importance and urgency on helping diabetes patients to control their glucoses. That is why, over the past few years, he has continuously simplified his findings about diabetes and to derive more useful formulas and simple tools for meeting the general public's interest on controlling chronic diseases and their complications to reduce their pain and probability of death.

Introduction
This article is Part 5 of the author's linear elastic glucose behavior study, which focuses on the predicted postprandial plasma glucose (PPG). This study is the combination and continuation of his previous four studies, Parts 1, 2, 3, and 4, on linear elastic glucose behaviors

Listed below are his two recently developed linear elastic glucose equations with two defined coefficients of GH-modulus and his third equation for the predicted PPG from combining these two equations together:

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Where Weight is the input component (similar to stress) and FPG is the output component (similar to strain).

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Young's modulus and the two biomedical coefficients (GH.f-modulus and GH.p-modulus) are reciprocal to each other.

The main objective of this study is to offer numerical proof for the PPG prediction accuracy using the above-mentioned equation (3) and based on his own health data collected from 7/1/2015 to 10/31/2020.

Methods
Background
To learn more about the author's GH-Method: math-physical medicine (MPM) methodology, readers can refer to his article to understand his developed MPM analysis method in Reference 1.

Highlights of his Related Research
In 2015 and 2016, the author decomposed the PPG waveforms (data curves) into 19 influential components and identified carbs/sugar intake amount and post-meal walking exercise contributing to approximately 40% of PPG formation, respectively. Therefore, he could safely discount the importance of the remaining ~20% contribution by the 16 other influential components.

In 2016, he utilized optical physics, big data analytics, and artificial intelligence (AI) techniques to develop a computer software

to predict PPG based on the patient's food pictures or meal photos. This sophisticated AI approach and iPhone APP software product have reached to a 98.8% prediction accuracy based on ~6,000 meal photos.

In March of 2017, he also detected that body weight contributes to over 85% to fasting plasma glucose (FPG) formation. Furthermore, in 2019, he identified that FPG could serve as a good indicator of the pancreatic beta cells' health status; therefore, he can apply the FPG value (more precisely, 97% of FPG value) to serve as the baseline PPG value to calculate the PPG incremental amount in order to obtain the predicted PPG.

In 2018, based on his collected ~2,500 meals and associated sensor PPG waveforms, he further applied the perturbation theory from quantum mechanics, using the first bite of his meal as the initial condition to extend and build an entire PPG waveform covering a period of 180 minutes, with a 95% of PPG prediction accuracy.

In 2019, all of his developed PPG prediction models achieved high percentages of prediction accuracy, but he also realized that his prediction models are too difficult for use by the general public. The above-mentioned sophisticated methods would be difficult for healthcare professionals and diabetes patients to understand, let alone use them in their daily life for diabetes control. As a result, he supplemented his complex models with a simple linear equation of predicted PPG (see References 2, 3, 4, and 12).

Here is his simple linear formula:
Predicted PPG= FPG * M1 + (carbs-sugar * M2) - (post-meal walking k-steps * M3)

Where M1, M2, M3 are 3 multipliers.

After lengthy research, trial and error, and data tuning, he finally identified the best multipliers for FPG and exercise as 0.97 for M1 and 5.0 for M3. In comparison with PPG, the FPG is a more stabilized biomarker since it is directly related to body weight. We know that weight reduction is a hard task. However, weight is a calmer and more stabilizing biomarker in comparison to glucose, which fluctuates from minute to minute. The influence of exercise (specifically, post-meal walking steps) on PPG (41% contribution and >80% negative correlation with PPG) is almost equal to the influence from the carbs/sugar intake amount on PPG (39% contribution and >80% positive correlation with PPG). In terms of intensity and duration, exercise is a simple and straightforward subject to study. Especially, normal-speed walking is a safe and effective form of exercise for the large portion of diabetes patients, particularly senior citizens.

The parameters, FPG and walking, have a lower chance of variation for the author. However, for some diabetes patients, he recommends them to keep the multiplier M3 as a variable if their exercise patterns are different and changing.

The relationship between food nutrition and glucose is a complex and difficult subject to fully understand and effectively manage due to many types of food and their associated carbs/sugar con-

tents. For example, in the author's developed food material and nutritional database, it contains over six million data. As a result, the author decided to implement two multipliers, M1 for FPG and M3 for exercise, as the two "constants" and keep M2 as the only "variable" in his PPG prediction equation and the linear elastic glucose research in this article.

The more simplified linear equation for predicted PPG is listed below:

*Predicted PPG= (0.97*FPG) + (Carbs&sugar * M2)- (post-meal walking k-steps * 5)*

He further created two new terms:

Term 1:
GH.p-modulus = M2

Term 2:
The incremental PPG amount= Predicted PPG - PPG baseline
*(i.e. 0.97 * FPG) + exercise effect*
*(i.e. walking k-steps * 5)*

The linear elastic PPG equation
GH.p-modulus
= (Incremental PPG)/(Carbs&sugar)
Recently, he developed his linear elastic FPG equation (Reference 11) as follows:

The linear elastic FPG equation
GH.f-modulus = (FPG) / (Weight)

Stress, Strain, & Young's Modulus
Prior to his medical research work, he was an engineer in the various fields of structural engineering (aerospace, naval defense, and earthquake engineering), mechanical engineering (nuclear power plant equipments, and computer-aided-design), and electronics engineering (computers, semiconductors, graphic software, and software robot).

The following excerpts come from internet public domain, including Google and Wikipedia:

"Strain - ε
Strain is the "deformation of a solid due to stress" - change in dimension divided by the original value of the dimension - and can be expressed as
ε = dL / L
where
ε = strain (m/m, in/in)
dL = elongation or compression (offset) of object (m, in)
L = length of object (m, in)

Stress - σ
Stress is force per unit area and can be expressed as
σ = F / A
where
σ = stress (N/m2, lb/in2, psi)

F = applied force (N, lb)
A = stress area of object (m2, in2)

Stress includes tensile stress, compressible stress, shearing stress, etc.

E, Young's Modulus
It can be expressed as:
$E = stress / strain = \sigma / \varepsilon = (F / A) / (dL / L)$

where
E = Young's Modulus of Elasticity (Pa, N/m2, lb/in2, psi) was named after the 18th-century English physicist Thomas Young.

Elasticity

Elasticity is a property of an object or material indicating how it will restore it to its original shape after distortion. A spring is an example of an elastic object - when stretched, it exerts a restoring force which tends to bring it back to its original length (Figure 1).
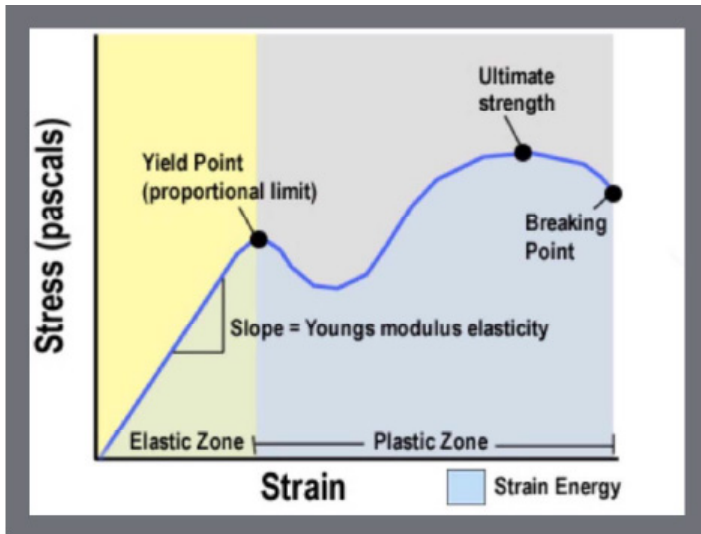

Figure 1: Stress-Strain-Young's modulus, Elastic Zone vs. Plastic Zone

Plasticity

When the force is going beyond the elastic limit of material, it is into a plastic zone which means even when force is removed, the material will not return back to its original state (Figure 1).

Based on various experimental results, the following table lists some Young's modulus associated with different materials:

Nylon:2.7 GPa
Concrete:17-30 GPa
Glass fibers:72 GPa
Copper:117 GPa
Steel:190-215 GPa
Diamond:1220 GPa

Young's modules in the above table are ranked from soft material (low E) to stiff material (higher E)."

Professor James Andrews taught the author linear elasticity at the University of Iowa and Professor Norman Jones taught him non-linear plasticity at Massachusetts Institute of Technology.These two great academic mentors provided him the necessary foundation knowledge to understand these two important subjects in engineering.

Data Collection

The author is a 73-year-old male with a 25-year history of T2D. He began collecting his carbs/sugar intake amount and post-meal walking steps on 7/1/2015. From 7/1/2015 to 10/31/2020 (1,962 days), he has collected 6 data per day, i.e. 1 FPG, 3 PPG, carb/sugar amount, and post-meal walking steps. He utilized these 11,772 data of 1,962 days to conduct his prior research work on the subject of linear elastic PPG study (Reference 7). In addition, on 5/5/2018, he started to use a continuous glucose monitoring (CGM) sensor device to collect 96 glucose data each day. Within this time period, he uses the same sensor device to collect 28 FPG data per day from 00:00 to 07:00 at each 15-minute time interval. Based on his prior research, this averaged sensor FPG value is within 1% of margin of error (i.e. 99% accuracy) from his measured FPG at the wake-up moment using finger-piercing and test strip method (Finger FPG).

The period of 7/1/2015 to 10/31/2020 is his "better-controlled" diabetes period, where his average daily glucoses is maintained at 116 mg/dL (<120 mg/dL). He named this as his "linear elastic zone" of diabetes health.It should also be noted that in 2010, his average glucose was 280 mg/dL and HbA1C was 10%, while taking three diabetes medications. The strong chemical interventions from various diabetes medications would seriously alter glucose physical behaviors. He called the period prior to 2015 as his "non-linear plastic zone" of diabetes health.

Results

Listed below are his two recently developed linear elastic glucose equations with two defined coefficients of GH-modulus and his third equation of predicted PPG from combining these two equations:

*(3) FPG = GH.f-modulus * Weight*

Where Weight is the input component (similar to stress) and FPG is the output component (similar to strain).

*(2) Incremental PPG= GH.p-modulus * Carbs&sugar*

Incremental PPG= Predicted PPG - (0.97 * FPG)+ (post-meal walking k-steps * 5)

When he combines above two linear elastic equations into one, he has the following new PPG prediction equation:

(3) Final PPG Prediction Equation
*Predicted PPG= (0.97 * GH.f-modulus * Weight) +(GH.p-modulus * Carbs&sugar) - (post-meal walking k-steps * 5)*

Where **GH.f-modulus** is a coefficient connecting Weight and FPG, and **GH.p-modulus** is a coefficient connecting Incremental

PPG and Carbs&sugar amount.Incremental PPG includes baseline PPG, containing FPG and Weight, and exercise effect. These two coefficients are directly depending on the severity level of patient's two chronic diseases, specifically obesity and diabetes. The suitable values of these two coefficients of GH-modulus can be estimated from a patient's values of Weight and HbA1C with a reasonably high accuracy.

The input data of this final PPG prediction equation would avoid using complicated and troublesome measuring devices, either finger piercing or CGM sensor. This prediction formula only needs weight, post-meal walking steps, and carbs/sugar intake amount.

However, estimation of carbs and sugar amount from food or meal is an overly complicated subject and not easy for most patients. The author utilized optical physics and artificial intelligence to develop a software for estimating carbs and sugar amount from the photos of food and meal, which achieved 98.8% prediction accuracy. However, it still requires a smartphone or computer, which is difficult for some patients in underdeveloped nations and senior citizens, who are not familiar with technology.Therefore, the author has continued his development effort on simplifying his prediction formula in order to cover a larger group of potential users while still maintaining its prediction accuracy.

Case A	lbs	FPG / Weight	gram	K-steps	Incremental PPG	Case A	mg/dL	mg/dL	Case A	PPG Prediction
Year	Weight	GH.f-modulus	Carbs/Sugar	Walking	GH.p-modulus	Year	Predicted PPG	Measured PPG	Year	Accuracy %
Y2015	173	0.71	14.46	3.681	1.6	Y2015	123	119	Y2015	97%
Y2016	173	0.68	15.47	4.110	1.8	Y2016	121	120	Y2016	99%
Y2017	174	0.69	14.19	4.440	1.6	Y2017	117	117	Y2017	100%
Y2018	171	0.66	15.47	4.518	1.9	Y2018	117	117	Y2018	100%
Y2019	170	0.66	13.19	4.038	1.8	Y2019	115	114	Y2019	99%
Y2020	171	0.59	12.34	4.345	2.4	Y2020	106	109	Y2020	103%
Average	172	0.67	14.19	4.192	1.9	Average	116	116	Average	100%

Figure 2:Raw data and calculated data

Figure 2 shows the raw data and his calculation of predicted PPG with accuracy percentages.He used his annual data from 2015 to 2020, except for Y2015 from 7/1/2015 to 12/31/2015 and Y2020 from 1/1/2020 to 10/31/2020.Listed below are the annual values of the (GH.f-modulus, GH.p-modulus, and PPG prediction %) for the author's case which reflect his severity levels of both obesity and diabetes, and PPG prediction accuracy percentage:

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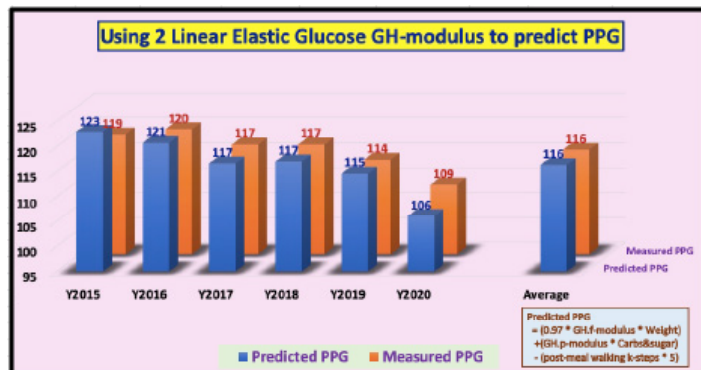Y2020: (0.59, 2.4, 103%)

Average: (0.67, 1.9, 100%)

Figure 3:Predicted PPG vs. Measured PPG (2015-2020)

Figure 3 depicts the direct comparison between his predicted annual PPG and his finger-piercing measured annual PPG. Although there are some small deviations from year to year, those deviations are within the range of +/- 3%.Over the 6- year period, both the predicted PPG and measured PPG are at 116 mg/dL. As mentioned above, this period is his "better-controlled" elastic range, which his developed linear elastic glucose behavior theory can be applied. If a patient has remarkably, high glucose levels or hyperglycemia condition, for example above 200 mg/dL, then this predicted PPG would start to deviate from the measured PPG.The author needs more reliable collected health data from some severe diabetes patients in order to continue his "nonlinear plastic glucose" research.
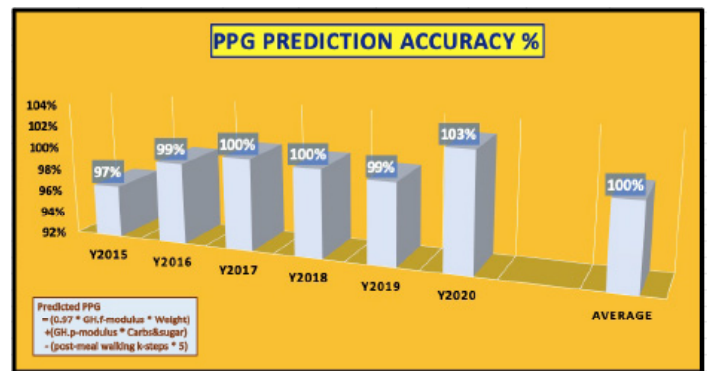

Figure 4:Prediction accuracy % of Predicted PPG vs. Measured PPG (2015-2020)

Figure 4 reveals the PPG prediction accuracy percentages over these 6 years.The annual PPG prediction accuracy are varying between 97% and 103%, but the overall 6-year average accuracy is 100%.

Conclusions
The author applied his linear elastic glucose theory of both FPG and PPG behaviors on the predicted PPG value with high accuracy in order to help other diabetes patients.The five major internal organs involved in glucose production are the brain, stomach, intestines, liver, and pancreas along with three major inter-organ systems including blood, nerves, and hormones. This study has further proved via a quantitative analysis that PPG level has a close

connection with FPG, weight (food quantity), carb/sugar intake (food quality), and exercise.

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