The GH-Method

Investigation of Linear Elastic Glucose Behavior with GH Modulus Linking Carbohydrates/Sugar Intake Amount and Incremental PPG Amount via Analogy of Young's Modulus from Engineering Strength of Materials Using GH-Method: Math-Physical Medicine, Parts 1, 2, 3 (No. 351a)

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Abstract

This article is a special research on the linear elasticity of glucose with his defined GH-modulus (or M2) cited in Reference 7. Main purposes of this particular study are two folds. First, it is to study the biomedical meaning of this GH modulus which depends on a patient's severity of type 2 diabetes (T2D) during a particular period of time. Second, it is to discover when its linear elastic features would appear, under what kind of conditions, and which way would be easier for patients to utilize in their daily glucose control. Here is the simple linear formula he defined previously in References 2, 3, 4 for predicting the postprandial plasma glucose (PPG): Predicted PPG = (FPG * 0.97) + (carbs/sugar grams * M2) - (post-meal walking K-steps * 5). In reference 7 (his paper number 346), he has connected this biomedical glucose prediction equation with a basic concept of stress and strain in engineering, along with the Young's modulus of strength of materials. Using his collected data of glucose, food, and exercise, he has demonstrated that a "pseudo-linear" relationship indeed exist between the carbs/sugar intake amount which is similar to the "stress" part on an engineering system; and the incremental PPG amount which is similar to the "strain" part of an engineering system. A newly defined coefficient of "GH-modulus", as the M2 multiplier for carbs/sugar intake amount, is very similar to the role of Young's modules on relating stress and strain in the subject of strength of materials, except they are reversed to each other. During his "better controlled" period of diabetes from 7/1/2015 to 10/13/2020, his averaged PPG is 116 mg/dL which is below 120 mg/dL, the considered normal range of diabetes conditions. Within certain range of glucose, the relationship between carbs/sugar intake amount and incremental PPG amount would be "linear" or "pseudo-linear". Otherwise, for severe T2D patients who has elevated PPG level above 180 mg/dL ("hyperglycemia") most of the time and suddenly dropped down to below 70 mg/dL ("insulin shock" or "hypoglycemia"), the relationship between food and PPG would then follow a nonlinear plastic pattern where his defined linear GH-modulus would not be applicable. By 2019, approximately 6% of worldwide population (or 463 million people) have diabetes. Although he believes that his linear elastic glucose behavior of GH modulus is only applicable for patient's glucose levels below 180 mg/dL and above 70 mg/dL, but it is already a wide enough range for lots of diabetes patients to use. In regard to nonlinear plastic zone, more hyperglycemic cases and associated data are required to collect and then conduct a further complex analysis. At least, this linear elastic glucose behavior is the first stage of getting sufficient information to move further into a more complicated nonlinear plastic glucose zone. For either fixed M2 or variable M2 values, a linear relationship between carbs/sugar intake and incremental PPG are observed. This defined GH-modulus (i.e. M2 value) is easier to be applied over a reasonable long period (e.g. 3 months or 4 months) in order to match with HbA1C value. Due to blood cells and liver cells are organic material, this GH-modulus is changing according to the severity of a patient's diabetes conditions. However, the author would like to recommend using a fixed GH-modules or M2 value within a period of 3 to 4 months due to the simplicity of calculation and usage.

Keywords: Type 2 diabetes; Biomedical; Postprandial plasma glucose; Fasting plasma glucose

Abbreviations: T2D: type 2 diabetes; PPG: postprandial plasma glucose; FPG: fasting plasma glucose; MPM: math-physical medicine

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1. INTRODUCTION

This article is a special research on the linear elasticity of glucose with his defined GH-modulus (or M2) cited in Reference 7. Main purposes of this particular study are two folds. First, it is to study the biomedical meaning of this GH modulus which depends on a patient's severity of type 2 diabetes (T2D) during a particular period of time. Second, it is to discover when its linear elastic features would appear, under what kind of conditions, and which way would be easier for patients to utilize in their daily glucose control.

Here is the simple linear formula he defined previously in References 2, 3, 4 for predicting the postprandial plasma glucose (PPG):

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In reference 7 (his paper number 346), he has connected this biomedical glucose prediction equation with a basic concept of stress and strain in engineering, along with the Young's modulus of strength of materials. Using his collected data of glucose, food, and exercise, he has demonstrated that a "pseudo-linear" relationship indeed exist between the carbs/sugar intake amount which is similar to the "stress" part on an engineering system; and the incremental PPG amount which is similar to the "strain" part of an engineering system. A newly defined coefficient of "GH-modulus", as the M2 multiplier for carbs/sugar intake amount, is very similar to the role of Young's modules on relating stress and strain in the subject of strength of materials, except they are reversed to each other.

During his "better controlled" period of diabetes from 7/1/2015 to 10/13/2020, his averaged PPG is 116 mg/dL which is below 120 mg/dL, the considered normal range of diabetes conditions. Within certain range of glucose, the relationship between carbs/sugar intake amount and incremental PPG amount would be "linear" or "pseudo-linear". Otherwise, for severe T2D patients who has elevated PPG level above 180 mg/dL ("hyperglycemia") most of the time and suddenly dropped down to below 70 mg/dL ("insulin shock" or "hypoglycemia"), the relationship between food and PPG would then follow a nonlinear plastic pattern where his defined linear GH-modulus would not be applicable.

By 2019, approximately 6% of worldwide population (or 463 million people) have diabetes. Although he believes that his linear elastic glucose behavior of GH modulus is only applicable for patient's glucose levels below 180 mg/dL and above 70 mg/dL, but it is already a wide enough range for lots of diabetes patients to use. In regard to nonlinear plastic zone, more hyperglycemic cases and associated data are required to collect and then conduct a further complex analysis. At least, this linear elastic glucose behavior is the first stage of getting sufficient information to move further into a more complicated nonlinear plastic glucose zone.

For either fixed M2 or variable M2 values, a linear relationship between carbs/sugar intake and incremental PPG are observed. This defined GH-modulus (i.e. M2 value) is easier to be applied over a reasonable long period (e.g. 3 months or 4 months) in order to match with HbA1C value. Due to blood cells and liver cells are organic material, this GH-modulus is changing according to the severity of a patient's diabetes conditions. However, the author would like to recommend using a fixed GH-modules or M2 value within a period of 3 to 4 months due to the simplicity of calculation and usage.

2. METHODS

2.1 Background

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

2.2 Highlights of his previous research

In 2015, 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 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 and then 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 mathematical models have achieved high percentages of prediction accuracy, but he also realized that his prediction models are too difficult to 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. Therefore, he tried to supplement his complex models with a simple linear equation of predicted PPG (see References 2, 3, and 4).

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 undertaking. But the weight is a far 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 much simpler and straightforward subject to study and deal with.

Therefore, for the author, these two parameters, FPG and walking, have a lower chance of variation. However, for other diabetes patients, the author still suggests them to keep the multiplier M3 as a variable if their exercise patterns are different and changing.

On the other hand, the relationship between food nutrition and glucose is an exceedingly complex and difficult subject to fully understand and effectively manage, since there are many types of food and their associated carbs/sugar contents. For example, the author's food nutrition database has already contained over six million data. As a result, the author decided to implement two multipliers, i.e. M1 for FPG and M3 for exercise, as two "constants" and keep M2 as the only "variable" in his PPG prediction equation and the linear elastic glucose study in this article.

This has further simplified his linear equation for predicted PPG as follows:

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

He also defines the following three new terms in terms 1, 2, and 3:

Term 1:
GH modulus = M2

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

Term 3:
GH modulus
= (Incremental PPG)/(Carbs&sugar)

2.3 Stress, strain, & Young's modulus

Prior to the past decade in his self-study and medical research work, he was an engineer in the fields of structural (aerospace and naval defense), mechanical (nuclear power plants and computer-aided-design), and electronics (computers and semiconductors). The following excerpt comes from the public domain, e.g. Google, 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

$\varepsilon = dL / L$

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

$\sigma = F / A$

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).

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 above table are ranked from soft material (low E) to stiff material (higher E)."

Professor James Andrews taught the author linear elasticity at University of Iowa and Professor Norman Jones taught him nonlinear plasticity at Massachusetts Institute of Technology. These two great academic mentors have taught him the foundation knowledge of these two important subjects.

In this particular study, the above-mentioned Term 4 is remarkably similar in"concept and format" to the stress-strain equation as shown below except GH modules and Young's modulus are reverse to each other.

GH modulus (i.e. M2)
=(Incremental PPG)/(Carbs&sugar)

Young's modulus E
= stress / strain
$= \sigma / \varepsilon$

Where incremental PPG is the incremental amount of predicted PPG (note: he also replaced the predicted PPG by measured PPG to conduct a sensitivity study of glucose behaviors).

The author visualizes the carbs/sugar intake amount as the stress (the force, cause, or stimulator) on his liver and the incremental PPG amount as the strain (the response, consequence, or stimulation) from the liver. The GH modulus (i.e. M2) is similar to the Young's modulus (i.e. E) which describes the "pseudo-linear" relationship existed between the carbs/sugar (stress) and incremental PPG (strain).

Conceptually, now, he is able to connect together the subject of liver glucose production in endocrinology with the subject of strength of materials in structural & mechanical engineering.

2.4 Data collection

The author (male case) is a 73 years old man who has 25 years history of type 2 diabetes (T2D) history. He began collecting his carbs/sugar intake amount and post-meal walking steps on 7/1/2015. From 7/15/2015 to 10/18/2020 (1,935 days), he has collected 6 data per day, 1 FPG, 3 PPG, carb/sugar, and post-meal walking steps. He utilized these 11,610 data of 1,935 days to conduct his prior research work on the subject of Part 1 of his linear elastic glucose 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.

The period of 7/1/2015 to 10/18/2020 is his "best-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 different diabetes medications. Please note that the strong chemical interventions from various diabetes medications would seriously alter the physical behaviors of glucose. Prior to 2015, he called that period as his "nonlinear plastic zone" of diabetes health.

The second set of data comes from his wife (female case) who has 22 years history of T2D. She began to collect her glucose data via finger-piercing method (finger glucose) since 1/1/2014. However, she does not keep a detailed record of her diet and exercise. Since both patients are almost eating the same meals prepared by the author, except the female case consumes more meats which partially causes her hyperlipidemia and hypertension conditions. From the diabetes research viewpoint, the author decided to use 80% of male case's carbs/sugar amount for her and use 50% of male case's post-meal walking steps for her. She also started to use the same CGM device to collect her sensor glucose data at the same rate of 96 data per day since 1/1/2020.

In order to maintain data consistency for a fair and accurate comparison, the author took both male data and female data from 1/18/2020 through 10/18/2020 and subdivided them into 9 equal-length monthly sub-periods to study their glucose fluctuation patterns and data (Part 2 study).

The third case, young case, is a younger male patient (47 years old) who has had 4 years history of T2D. He has started to collect his glucose data via the same CGM sensor device since 3/18/2020. Through telephone interviews, the author discovered that during the past 7-months period, his averaged carbs/sugar intake amount is about the same as the male case, and his averaged post-meal walking steps is at ~25% level of male case.

In order to maintain data consistency for a fair and accurate comparison, the author took CGM sensor glucose data from male, female, and young cases from 3/18/2020 through 10/18/2020 and subdivided them into 7 equal-length monthly sub-periods to study their glucose fluctuation patterns and data (Part 3 study).

One of the reasons of using sensor glucose data instead of finger glucose is that sensor glucoses are 13% to 18% higher than finger glucoses in average. So, using sensor data would be more conservative in terms analyzing diabetes severity. Finally, the author compares these three sets of GH-modulus values and data patterns from the viewpoint of diabetes severity.

3. RESULTS

3.1 Part 1: fixed & variable M2 of 1 patient

The author has recorded his glucose and weight data since 1/1/2012 and then began collecting carbs/sugar intake amount and post-meal walking steps on 7/1/2015. This period coincides with his "best-controlled" diabetes period, where his average daily glucoses reduced to 116 mg/dL which is under 120 mg/dL (i.e. the normal range) without taking any medications. 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 (i.e. strong chemical interventions). Prior to 2015, he called that period as his "nonlinear plastic zone" of diabetes health.

From 7/15/2015 to 10/13/2020 (1,930 days), he has collected 6 data per day, 1 FPG, 3 PPG, carb/sugar, and post-meal walking steps. He utilized these 11,580 data and then organized them into 6 years to conduct his annual calculations. The collected raw data and two sets of calculations are shown in Figure 2. The calculations in this table figure use two different sets of M2 values.

In Case A, calculation is based on variable M2 values each year in order to obtain 100% of the PPG prediction accuracy for every year in this period. The 100% accuracy indicates that the annual predicted PPG is identical to the annual measured PPG. In Case B, calculation is based on a constant value of 1.82 for M2 (using the 6-years' average) to obtain six different annual PPG prediction accuracies ranging from 93% to 103%. Figure 3 illustrates calculated data table of these two cases, Case A with different M2 and Case B with constant M2.

Figure 4 and Figure 5 show the graphic results of Case A (variable M2) and Case B (constant M2) based on the calculated data table as show in Figure 3.

Figure 4 depicts the results from using variable M2 values to achieve a 100% match between the predicted PPG and measured PPG of each year.

Listed below are the values for the M2 multiplier (i.e. GH-modulus) for each year:

Year 2015 - 1.56
Year 2016 - 1.76
Year 2017 - 1.59
Year 2018 - 1.87
Year 2019 - 1.75
Year 2020 - 2.41
Averaged - 1.82

In Figure 5, it reflects the results from using a constant GH-modulus (M2) of 1.82 to achieve different predicted PPG values from the measured PPG values, with different prediction accuracy for each year (from 93% to 103%).

Listed below are the values of the prediction accuracy for each year:

Year 2015 - 103%
Year 2016 - 101%
Year 2017 - 103%
Year 2018 - 99%
Year 2019 - 101%
Year 2020 - 93%
Averaged - 100%

In fact, the prediction accuracies varying between 93% to 103% with a 6-years averaged accuracy of 100% are acceptable for the purpose of practical glucose control for diabetes patients. This is similar to a diabetes patient's situation of glucose prediction accuracy ranging from 112 mg/dL (93%) to 124 mg/dL (103%) using a normal dividing line of 120 mg/dL (100%).

Figure 6 shows an x-y data diagram with a "pseudo-linear" relationship between x-values of carbs/sugar multiplied by M2, and y-values of the incremental PPG due to FPG and exercise as defined in the following equation:

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

The data ranges of x-axis and y-axis are from 20 to 32. It is obvious that the six-annual data "almost" form a straight line with a slope of 45% and a very small degree of deviations which is why the author calls it a "pseudo-linear" relationship. This is similar to the "elastic zone" of the stress-strain-Young's modulus diagram in strength of materials of structural and mechanical engineering (Figure 1). This linear relationship makes the task of PPG prediction and diabetes control much easier.

3.2 Part 2: fixed & variable M2 of two patients

Fixed M2 case

Figure 8 shows the collected raw data with a fixed M2 values for calculating both predicted PPG and prediction accuracy percentages. In this table, the author utilized two different fixed values of M2 for male case (3.6) and female case (2.6), respectively to calculate both x- and y- components of his "linear elastic glucose" equation. The comparison between the male case M2 value of 3.6 and the female case M2 of 2.6 revealed the individual severity of their respective T2D conditions. The male case indicates a more severe diabetes patient who requires higher M2 value to increase his predicted PPG in order to match his higher measured PPG value.

Again, the linear elastic glucose equation using predicted PPG is listed below:

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

The "x-component" of the linear elastic glucose equation is:

(carbs&sugar * M2);

While the "y-component" of the linear elastic glucose equation is:

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

Due to the linearity characteristics of this equation, the relationship between the x-component and y-component is always guaranteed to be "linear". However, these two different fixed M2 values would result into different data ranges of x and y components. Figures 9 and 10 show these two different fixed M2 values and corresponding data ranges for male case and female case, respectively.

The male case with the fixed M2 of 3.6, both x and y are within the range of 35 to 58 with an average value of 44 is shown in Figure 9. The female case with the fixed M2 of 2.6, both x and y are within the range of 22 to 34 with an average value of 26 is observed in of Figure 10.

In summary, the higher M2, the higher x and y values become, and the higher predicted and measured PPG values are. The key point from these two figures is that the M2 values are varying based on a patient's body conditions (blood, liver, and pancreas). This is similar to the different organic materials from the different Young's modules (E) values, such as nylon's E ~3 versus steel's E ~200.

Listed below are the values of the prediction accuracy for male and female for each month. Please note that the prediction accuracy percentage varies with the fixed M2 input, however, their prediction accuracies are 100% for the total period of 9 months for both male case and female case which is the purpose of selecting these two fixed M2 values. However, this approach will cause some degree of sacrifice on PPG prediction's accuracy during each month. It should be noted that the prediction accuracy range are 88%-111% and 93%-108% for male case and female case, respectively.

1/18 - 2/18: 101% & 97%
2/18 - 3/18: 97% & 99%
3/18 - 4/18: 98% & 95%
4/18 - 5/18: 111% & 108%
5/18 - 6/18: 101% & 107%
6/18 - 7/18: 88% & 93%
7/18 - 8/18: 100% & 95%
8/18 - 9/18: 102% & 101%
9/18 - 10/18: 98% & 106%
2020 Average: 100% & 100%

Variable M2 case

Figure 11 illustrates the collected raw data to be used in his variable M2 case of calculations. In this table, the author utilized variable value of M2 for each month in order to make the calculated x-component values to match with the calculated y-components values during each monthly sub-period; therefore, to "force" the predicted PPG value to match with the measured PPG value in each month. As a result, a "pseudo-linear" relationship between x-component and y-component could be created and observed.

This forced "pseudo-linear" relationship makes sense in the biomedical field since red blood cells and liver cells are organic materials which are different from those inorganic materials in the engineering systems, such as rubber, concrete, or steel. The human organ cells are not only organic but also have different lifespans, where they can mutate, change, repair, or die. For example, the lifespan of the red blood cells is 115 to 120 days, the lifespan of liver cells is 300 to 500 days, and the lifespan of pancreatic beta cells is unknown with slightly adaptive change (this is why pancreatic beta cells self-repair process is very slow, about 2.7% per year for the author). Not all of the body cells die at the same moment. At any given instance, an organ would have different combinations of new cells, sick cells, dying cells, and mutated cells, mixing together. It is complex and an extraordinarily situation; therefore, the author has chosen different M2 values for different months in order to achieve his prediction accuracies for all sub-periods. This would be a reasonable approach in proceeding with this biomedical research.

In the previous paragraph, the fixed M2 difference between the male case of 3.6 versus the female case of 2.6 is based on the severity of their T2D between patients. Furthermore, in this paragraph, it has demonstrated that the variable M2 differences of different months are resulted from the T2D conditions varying month to month for each patient. This means that glucose is a "dynamic" function instead of being a "static" function. The above discussions are the major differences between the linear elasticity organic glucoses and the traditional linear elasticity of strength of inorganic engineering materials.

For conducting a further sensitivity analysis, he used the measured PPG to replace the predicted PPG in the linear elastic glucose equation as show below:

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

The "x-component" of the linear elastic glucose equation is:

(carbs&sugar * M2);

While the "y-component" of the linear elastic glucose equation is:

(Measured PPG - (FPG * 0.97) + (post-meal walking k-steps * 5)

By examining the variable M2 values, over 9 monthly sub-periods, the male case has M2 range from 2.8 to 5.2 with an average of 3.7 value, and the female case has M2 range from 1.9 to 3.6 with an average of 2.7 value (Figure 5). Please note the minor difference between fixed M2 of 3.6 versus 2.6 and variable M2 of 3.7 versus 2.7 which are caused by rounding off in the numerical analysis.

For the male case with variable M2, both x and y components are within the range of 37 to 51 with an average value of 45. For the female case with variable M2, both x and y components are within the range of 18 to 32 with an average value of 26.

In summary, similar to the fixed M2 case, for most of the months, the higher variable M2, the higher x and y values become, and the higher predicted and measured PPG values are. The key point from these two figures is that the monthly M2 values are dependent on the patient's body conditions (combination of blood, liver, and pancreas) for that particular month.

Figures 12 and 13 have graphically demonstrated the linear elastic glucoses data from Figures 8 and 9.

Listed below are the values of the individual M2 multiplier (i.e. variable GH-modulus) for each month in 2020, in the order of (male case vs. female case).

1/18 - 2/18: 3.5 vs. 3.0
2/18 - 3/18: 3.9 vs. 2.7
3/18 - 4/18: 3.8 vs. 3.1
4/18 - 5/18: 2.8 vs. 1.9
5/18 - 6/18: 3.5 vs. 1.9
6/18 - 7/18: 5.2 vs. 3.6
7/18 - 8/18: 3.6 vs. 3.2
8/18 - 9/18: 3.4 vs. 2.5
9/18 - 10/18: 3.8 vs. 1.9
2020 Average: 3.7 vs. 2.7

The purpose in selecting variable M2 values for each of the 9 monthly sub-periods is to achieve 100% match between x- component and y-component for both male case and female case.

3.3 Part 3: variable M2 of three patients

Figure 14 shows the raw data collected from the three cases and their respective predicted PPG values of each sub-period.

Figure 15 lists a data table of calculated x- and y- components, where

x is (carbs&sugar * M2) and y is (measured PPG -(FPG * 0.97) + (walking k-steps * 5).

This table provides the most suitable GH-modulus (i.e. M2) values for each month which allows the predicted PPG to match the measured PPG via trial-and-error.

The 7-month average value of each monthly M2 variables (i.e, GH-modulus) are 3.7, 2.6, and 1.0, and with an average measured PPG values at 122 mg/dL, 114 md/dL, and 109 mg/dL, for Case A, Case B, and Case C, respectively, which are ranked according to the severity of their diabetes conditions.

Listed below are the values of the individual M2 multiplier (i.e. GH-modulus) for each of the 7 months in 2020 which are listed in the order of (Case A, Case B, Case C):

3/18 - 4/18: (3.8, 3.1, 1.3)
4/18 - 5/18: (2.8, 1.9, 0.6)
5/18 - 6/18: (3.5, 1.9, 0.7)
6/18 - 7/18: (5.2, 3.6, 0.7)
7/18 - 8/18: (3.6, 3.2, 1.4)
8/18 - 9/18: (3.4, 2.5, 1.2)
9/18 - 10/18: (3.8, 1.9, 1.4)
Variable M2: (3.7, 2.6, 1.0)
Fixed M2: (3.6, 2.6, 1.0)

Case A with the fixed M2 as 3.6, both x and y are within the range of 38 to 48 with an average value of 45 are observed in Figure 16. Case B with the fixed M2 as 2.6, both x and y are within the range of 18 to 32 with an average value of 25 are observed in Figure 17. Case C with the fixed M2 as 1.0, both x and y are within the range of 11 to 17 with an average value of 13 are observed in Figure 18.

In summary, the higher the M2, the higher values of both x (carbs/sugar intake amount) and y (incremental PPG amount) become, and the higher predicted and measured PPG values are. The key conclusion from these three clinical observations is that the M2 values are varying based on patients' body conditions (blood, liver, pancreas), especially their diabetes severity. This is similar to the different inorganic materials having the different Young's modules values, such as nylon ~3 versus steel ~200.

4. DISCUSSION

4.1 Part 1: one patient

The author was a severe type 2 diabetes patient since 1995. He suffered many life-threatening diabetic complications during the period of Y2000 to Y2012. He started to self-study and research on diabetes and food nutrition since 2010 when his average glucose value was 280 mg/dL and HbA1C 10%, and suffered 5 cardiovascular episodes. He collected his diet and exercise data since 6/1/2015. After 2015, his diabetes conditions have been under control via a stringent lifestyle program; therefore, in this study, he used his collected big data of lifestyle details and glucoses to conduct his rather completed numerical analysis. From 7/1/2015 to 10/13/2020, his diabetes conditions have fallen into a linear "elastic" zone (averaged glucose 116 mg/dL with some peaks). This also suggests that his PPG would fall off to a reasonable range (around 120 mg/dL or below) when he consumes less amounts of carbs/sugar and exercise adequately.

On the other hand, during the period of 2000-2010, when his diabetes was totally out of control, he believes that his case should be belonging to a "nonlinear plastic" zone, or at least a "bi-linear plastic" zone, meaning his PPG would remain at a certain elevated level even if he reduced or stopped the intake of carbs/sugar. Worse than just having "elevated glucoses" (hyperglycemia i.e. >180 mg/dL), he could suffer from hypoglycemia (glucose <70 mg/dL) leading to insulin shock and eventually sudden death. However, due to the lack of sufficient data collection, he cannot conduct a similar detailed and completed numerical analysis to prove his suspicion of "nonlinear plastic" zone. He can only try to use his scattered data collection from 2010 to 2014 to obtain a guesstimated observation and some partial conclusions.

As shown in Figure 7, he displayed an x-y diagram of predicted PPG versus measured PPG over both periods, the smaller area of linear elastic period of 2015-2020 and bigger area of nonlinear plastic period of 2010-2014.

The comparison between these two zones are interesting, but yet he needs to find other ways to collect data and prove his suspicion on the linkage between his glucose spikes and fluctuations (i.e. nonlinearity) of glucoses in the plastic zone and carbs/sugar intake amount in order to compare against his controlled glucoses situations of the pseudo-linear elastic zone.

In his research papers published since 2019, he has proven that his pancreatic beta cells' insulin capability of production and quality have been self-repaired at an annual rate of 2.7% (References 5 and 6). It means that 16% of his insulin production and quality problems have been repaired since 2015 which is in the elastic zone and 27% repaired since 2011 which covers both partial plastic and elastic zones. This type of "organic" cells' regeneration capability and biomedical phenomena was unknown to him when he was an engineer and only dealing with various "inorganic" materials, such as metal, concrete, and silicon. As a result, since 2010, he has been fascinated and worked with the various stimulators and complex stimulations of the biomedical system. The more research work he performs, the more unknown phenomena enter into his eyes and the more questions enter into his mind, causing him to search for more and better solutions.

4.2 Part 2: two patients

This "linear elastic glucose" study started from the verification and improvement for the predicted PPG through his previously defined simple formula of PPG prediction. The author has learned from his engineering background that a linear system approach would be the easiest way to study a relationship between causes and consequences. Therefore, he started to investigate the similarity between elastic glucose system and elastic engineering system using Young's modulus and GH-modulus as his pair of analogy models. Nevertheless, he has never forgotten his ultimate objective is to identify an easier application model with a higher PPG prediction accuracy in order to help other diabetes patients while maintain the basic requirement of science to seek for truth with high precision.

Either using a fixed M2 value to achieve a high accuracy over a total period of 9 months or using monthly variable M2 values to achieve high accuracies for every monthly sub-period, he has observed a linear relationship existing between carbs/sugar intake amount and incremental PPG amount (including predicted or measured PPG, FPG, and exercise). More importantly, he still maintains an extremely high PPG prediction accuracy from using both approaches.

One important viewpoint is that glucose is an organic material which consists of nonlinear and dynamic functional behaviors in its nature. Therefore, in order to fully understand and be able to describe its behavior accurately, a research using a nonlinear plastic model is needed. However, at present time, similar to linear elasticity engineering applications, this linear elastic glucose behavior study already covers a sufficient scope of biomedical applications, and it is useful. As a counterpart example, many T2D patients are either in the pre-diabetes range (PPG value at 120 to 140 mg/dL) or their glucose levels fall below the hyperglycemia range (i.e., glucose at 180 mg/dL or lower). This simpler "linear glucose model" can be extremely useful for many diabetes patients worldwide already.

Depending on the approach, either the overall period's fixed M2 or sub-period's variable M2, it would be easier for diabetes patient to use this linear elastic glucose behavior for their glucose control. The author prefers the fixed M2 model since traditional internal medicine utilizes the HbA1C model. The HbA1C value is remarkably close to the average glucose over a 90-day period (conventionally) or over 120-day period (the author's defined model based on red blood cells life span). Besides, calculating or guess-estimating a single M2 value is much easier and acceptable by patients than using multiple M2 values for every sub-period calculation.

4.3 Part 3: three patients

In the table of raw data shown in Figure 14 and the calculation of x, y, variable M2 shown in Figure 15, plus the three graphic figures of 16, 17, and 18, the author utilized variable M2 values for each month in order to make the calculated x-component values to match with the calculated y-components values during each monthly sub-period; therefore, to "force" the predicted PPG value to match with the measured PPG value in each month. As a result, a linear or "pseudo-linear" relationship between x-component and y-component could be created and observed.

This forced "pseudo-linear" relationship makes sense in the biomedical field since red blood cells and liver cells are organic materials which are different from those inorganic materials in the engineering systems, such as rubber or steel. The human organ cells are not only organic but also have different lifespans, where they can mutate, change, repair, or die. For example, the lifespan of the red blood cells is 115 to 120 days, the lifespan of liver cells is 300 to 500 days, and the lifespan of pancreatic beta cells is unknown with a slightly adaptive change. As indicated in his previous research, the pancreatic beta cells' self-repair process is very slow, taking approximately 2.7% per year for the author. Not all of the body cells die at the same moment. At any given instance, an organ would have different combination of new cells, sick cells, dying cells, and mutated cells that can mix together. It is an overly complex and extraordinarily situation; therefore, the author has chosen variable M2 values for different months in order to achieve his prediction accuracies for all sub-periods. This would be a reasonable approach for this particular biomedical research. These data have demonstrated that the variable M2 values of different months resulted from the T2D conditions varying month to month for each patient, precisely the combined situation of liver, blood, and pancreas. This means that glucose is a very "dynamic" function instead of being a "static" function. The above discussions are the major differences between the linear elasticity organic glucoses and the traditional linear elasticity of strength of inorganic engineering materials.

5. CONCLUSION

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

The human body is the most complex system he has dealt with. However, 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 way we take. This is the foundation of the GH-Method: math-physics medicine.

The author has spent four decades as a practical engineer, but he does understand the importance of basic concepts, sophisticated theories, and practical equations which serve as the necessary background of all kinds of applications. Therefore, he spent his time and energy to investigate glucose related subjects using variety of methods he learned 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 derive more useful formulas or practical tools for meeting the general public's interest on controlling chronic diseases and their complications to reduce their pain and death threat probability.

6. REFERENCES

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