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Investigation of Linear Elastic Glucose Behavior with GH-Modulus Linking Carbohydrates/Sugar Intake and Incremental PPG via an Analogy of Young's Modulus from Theory of Elasticity and Engineering Strength of Materials using GH-Method: Math-Physical Medicine, Parts 1, 2, and 3 (No. 352)

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Abstract

This article is an extension work of his previous research result of a "simple linear equation of predicted postprandial plasma glucose (PPG)" as shown below:

*Predicted PPG= (FPG * 0.97) + (carbs/sugar grams * M2) - (post-meal waking K-steps * 5)*

This article contains special research on the linear elasticity of glucose behaviors with his newly defined GH-modulus (M2) cited in References 7, 8, and 9. The author makes an analogy of stress, strain, and Young's models from engineering strength of materials and theory of elasticity with carbs/sugar (carbs) intake amounts, incremental PPG (PPG delta) and GH-modulus of endocrinology and biomedical science. There are three parts to the study.

In the first part, by using the 6 years of collected data, he attempts to prove a "linear elastic relationship" existing between carbs and PPG delta via the existence of GH-modulus as the "slope" of their straight-line linear relationship.

For the second part, through 9-months data of two diabetes clinical cases, he discovered that the magnitude for the GH-modulus is proportional to the diabetes severity of the patients. This means that the GH-modulus is clearly "material" dependent on the patient's conditions.

In the third part, by examining 7- months data of three diabetes clinical cases, he uncovered the magnitude of GH-modulus varying month to month for all of these three patients. As a result, the GH-modulus is evidently "time" dependent as well.

Part 1 Summary

It is obvious that the six-annual data "almost" form a straight line with a slope of 45% between carbs and PPG delta. The author describes the linear phenomenon and data points having small deviations from the straight-line, as a "pseudo-linear" relationship. This is similar to the "elastic zone" of the Stress-Strain-Young's modulus diagram in theory of elasticity and strength of materials of structural and mechanical engineering (Figure 1). This linear relationship makes the task of incremental PPG prediction through diabetes control via diet much easier.

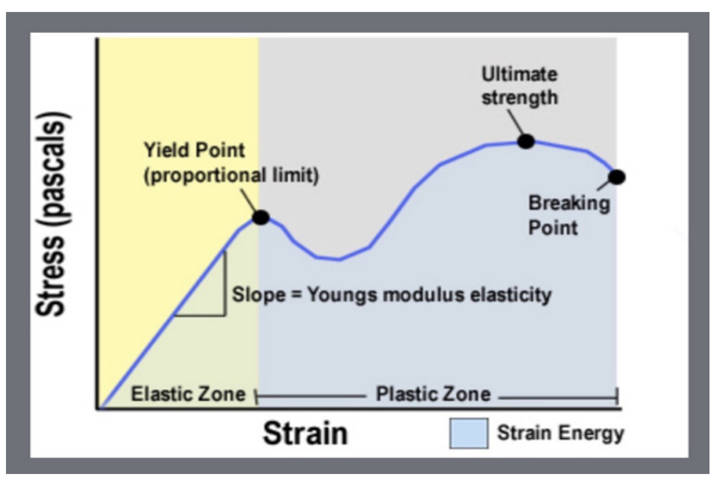


Figure 1: Stress-Strain-Young's modulus, Elastic Zone vs. Plastic Zone

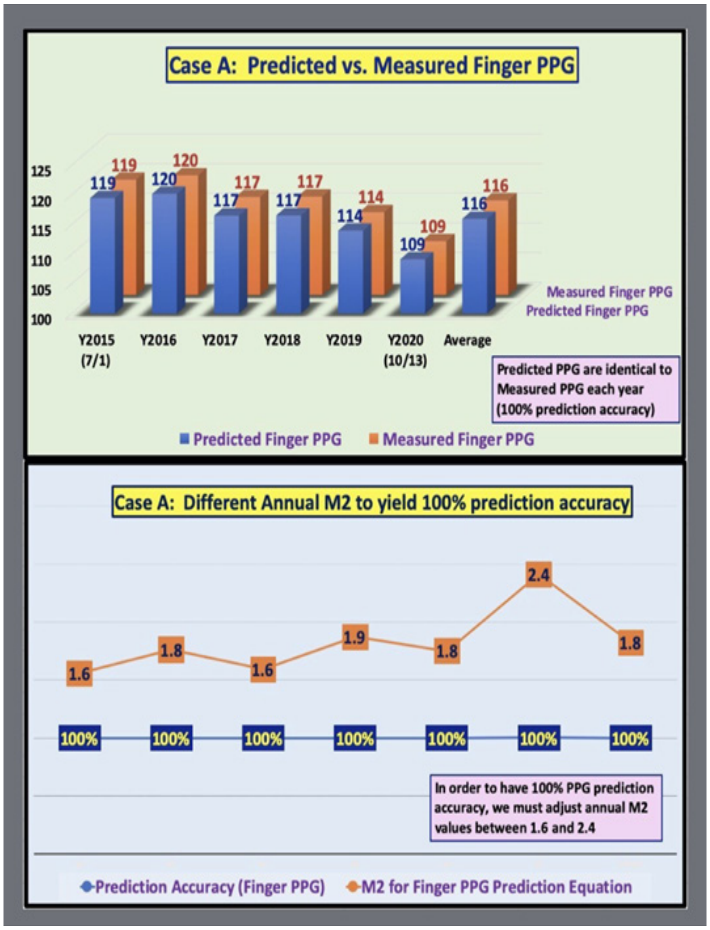


Figure 1-1: (Part 1) Calculated PPG prediction using Case A (variable M2) to have 100% prediction accuracy for each year of the period of 7/1/2015 - 10/13/2020

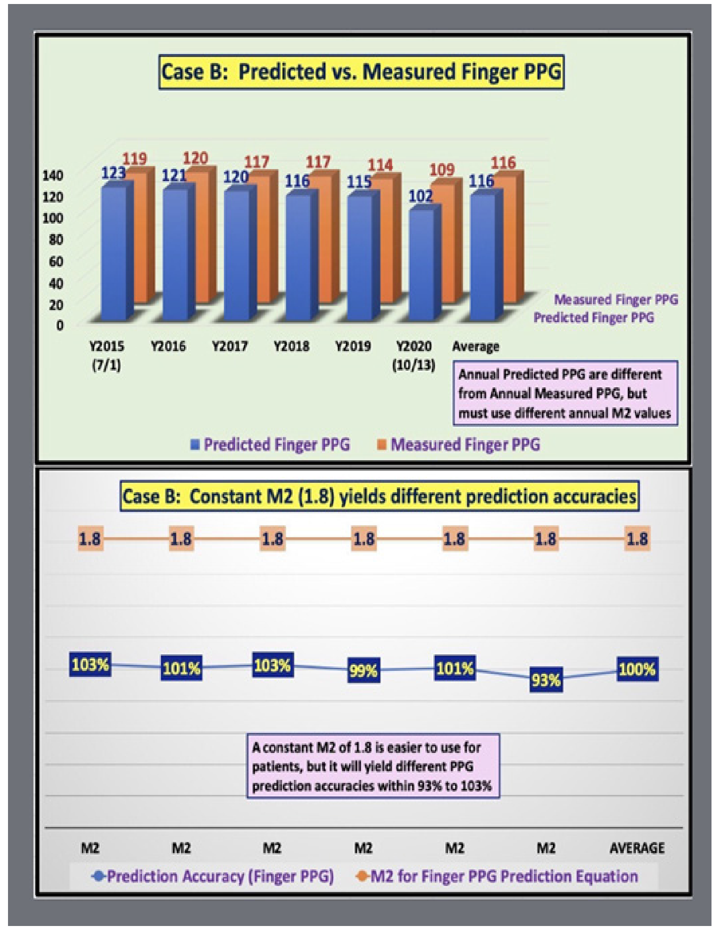


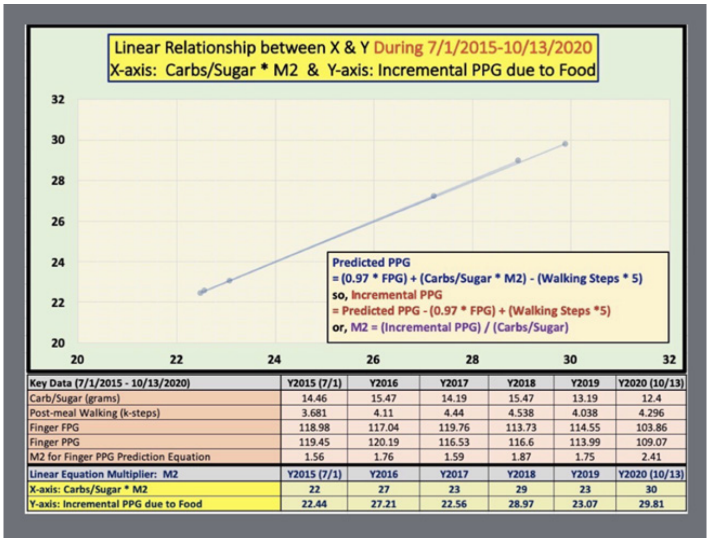
Figure 1-2: (Part 1) Calculated PPG prediction using Case A (constant M2) to have different prediction accuracy for each year (between 93% and 103%) of the period of 7/1/2015 - 10/13/2020

Part 2 Summary

For most of the 9 months, the higher the variable M2, the higher x and y values become, and the higher predicted and measured PPG values are. The key point is that the monthly M2 values (i.e., GH-modulus) are dependent on the patient's body conditions, a combination of blood, liver, and pancreas, of that particular month.

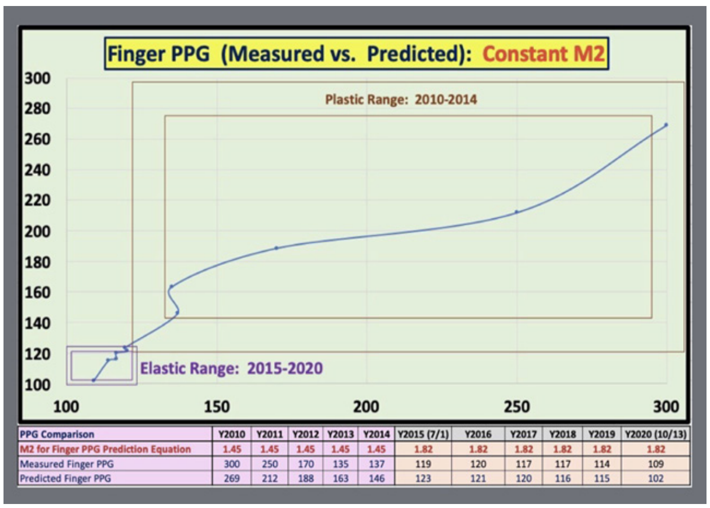
Part 3 Summary

The 7-month average values 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. They are ranked according to the severity of their diabetes conditions. 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 the patients' conditions, especially their diabetes severity that is blood, liver, and pancreas. It also indicates that GH-modulus are varying on the time scale because the body organ cells are "organic" materials.



Key Data (7/1/2015 - 10/13/2020)	Y2015 (7/1)	Y2016	Y2017	Y2018	Y2019	Y2020 (10/13)
Carb/Sugar (grams)	14.46	15.47	14.19	15.47	13.19	12.4
Post-meal Walking (k-steps)	3.681	4.11	4.44	4.538	4.038	4.296
Finger FPG	118.98	117.04	119.76	113.73	114.55	103.86
Finger PPG	119.45	120.19	116.53	116.6	113.99	109.07
M2 for Finger PPG Prediction Equation	1.56	1.76	1.59	1.87	1.75	2.41
Linear Equation Multiplier: M2	Y2015 (7/1)	Y2016	Y2017	Y2018	Y2019	Y2020 (10/13)
X-axis: Carbs/Sugar * M2	22	27	23	29	23	30
Y-axis: Incremental PPG due to Food	22.44	27.21	22.56	28.97	23.07	29.81

Figure 1-3: (Part 1) A "pseudo-linear" relationship between x-values and y-values during the "linear elastic" zone of 2015-2020



PPG Comparison	Y2010	Y2011	Y2012	Y2013	Y2014	Y2015 (7/1)	Y2016	Y2017	Y2018	Y2019	Y2020 (10/13)
M2 for Finger PPG Prediction Equation	1.45	1.45	1.45	1.45	1.45	1.82	1.82	1.82	1.82	1.82	1.82
Measured Finger PPG	300	250	170	135	137	119	120	117	117	114	109
Predicted Finger PPG	269	212	188	163	146	123	121	120	116	115	102

Figure 1-4: (Part 1) Discussion of variety relationship between predicted PPG and measured PPG during 2010-2020 (both "pseudo-linear elastic" zone and "nonlinear plastic" zone)

Here are the main conclusions of this article:

First, by using an analogy from the theory of elasticity and engineering strength of material, the author has identified a linear relationship existing between carbs and PPG delta with a newly defined GH-modulus, similar to a linear relationship between stress and strain with Young's modulus.

Second, based on two diabetes patients' 9-month data, he has proven that the magnitude of GH-modulus is directly proportional to the *diabetes severity* of the patients.

Third, by utilizing three diabetes patients' 7-month data, he has confirmed that the magnitude of the monthly GH-modulus is directly proportional to the diabetes severity of *that particular month* for each patient.

Fourth, these linear elastic glucose behavior findings are probably *applicable to a glucose range from 70 mg/dL* to 180 mg/dL which covers most situations for a diabetes patient. For glucose values falling outside the range, a nonlinear plastic glucose behavior study is needed.

Introduction

This article is an extension work of his previous research result of a "simple linear equation of predicted postprandial plasma glucose (PPG)" as shown below:

*Predicted PPG= (FPG * 0.97) + (carbs/sugar grams * M2) - (post-meal waking K-steps * 5)*

This article contains special research on the linear elasticity of glucose behaviors with his newly defined GH-modulus (M2) cited in References 7, 8, and 9. The author makes an analogy of stress, strain, and Young's models from engineering strength of materials and theory of elasticity with carbs/sugar (carbs) intake amounts, incremental PPG (PPG delta) and GH-modulus of endocrinology and biomedical science. There are three parts to the study.

In the first part, by using the 6 years of collected data, he attempts to prove a *"linear elastic relationship"* existing between carbs and PPG delta via the existence of GH-modulus as the "slope" of their straight-line linear relationship.

For the second part, through two 9 months of diabetes clinical cases, he discovered that the magnitude for the GH-modulus is proportional to the diabetes severity of the patients. This means that the GH-modulus is clearly *"material"* dependent on the patient's conditions.

In the third part, by examining 7 months of data from three diabetes clinical cases, he uncovered the magnitude of GH-modulus varying month to month for the three patients. As a result, the GH-modulus is evidently *"time"* dependent as well.

Methods

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.

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 (a simplified single variable with first-order polynomial function) from quantum mechanics, using the first-bite of his meal as the initial condition and then extend to build the entire predicted 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 recommends for them to keep the multiplier M3 as a variable if their exercise patterns are complex, different, and fluctuating.

On the other hand, the relationship between food nutrition and glucose is an exceedingly complex and difficult subject or task 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 nutritional database contains over six million data. As a result, the author decided to implement two multipliers, 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 particular article.

Here is the simplified 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)

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 excerpts come from 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
$\varepsilon = dL / L$
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:
$E = \text{stress} / \text{strain} = \sigma / \varepsilon = (F / A) / (dL / L)$
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 of the 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

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

Professor James Andrews taught him linear elasticity at the University of Iowa and Professor Norman Jones taught him nonlinear plasticity at Massachusetts Institute of Technology. These two great academic mentors have trained him with 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 that the GH modules and Young's modulus are reciprocal to each other due to their switched abscissa and ordinate.*

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

Young's Modulus E*= stress / strain=* σ / ε

Where the Incremental PPG is the incremental amount of predicted PPG, i.e. PPG delta. Note: at times, he may also replace the predicted PPG by the measured PPG in order to conduct a sensitivity study of the glucose behaviors.

The author visualizes the carbs as the stress (the force, cause, or stimulator) on his liver and the PPG delta 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 existing between the carbs (stress) and PPG delta (strain).

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

Data Collection

The author (Case A) is a 73-year-old male with a 25-year 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 in Part 1 of his linear elastic glucose study (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.

From 7/1/2015 to 10/18/2020 is his "best-controlled" diabetes period, where his average daily glucoses are maintained at 116 mg/dL (<120 mg/dL). He named this as his "linear elastic zone" of diabetes health. In 2010, his average glucose was 280 mg/dL and HbA1C was 10%, while taking three different diabetes medications (i.e., under very severe type 2 diabetes conditions). Please note that 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 (Case B) with a 22-year 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 that she consumes more meat which partially affects her hyperlipidemia and hypertension conditions. From the diabetes research viewpoint, the author decided to use 80% of Case A's carbs/sugar amount and use 50% of Case A's post-meal walking steps for her. She also started to use the same brand of CGM device to collect her sensor glucose data at the same rate of 96 data per day starting on 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 monthly sub-periods of equal length to study their glucose fluctuation patterns and data (Part 2 study).

The third case, Case C, is a 47-year-old male patient with a 4-year history of T2D. He has started to collect his glucose data via the same brand of CGM sensor device on 3/18/2020. Through telephone interviews, the author discovered that during the past 7-month period, his average carbs/sugar intake amount is about the same as Case A and his average post-meal walking steps is at ~25% level of Case A.

In order to maintain data consistency for a fair and accurate comparison, the author took the CGM sensor glucose data from Cases A, B, and C from 3/18/2020 through 10/18/2020 and subdivided them into 7 monthly sub-periods of equal lengths to study their glucose fluctuation patterns and data (Part 3 study).

One of the reasons for using the sensor glucose data is that they are 12.4% (daily glucose) to 16.3% (PPG) higher than finger glucoses on average. Therefore, using the sensor data would be more conservative in terms analyzing diabetes severity. As a result, the author could compare these three sets of GH-modulus values and data patterns from the viewpoint of diabetes severity.

Results

Part 1
Fixed & Variable M2 of 1 Patient

The data calculations in this part use two different sets of M2 values. In Case A, the calculation is based on variable M2 values annually 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, the calculation is based on a constant value of 1.82 for M2 (using the 6-year average) to obtain six different annual PPG prediction accuracies ranging from 93% to 103%.

Figure 1 and Figure 2 show the graphic results of Case A (variable M2) and Case B (constant M2).

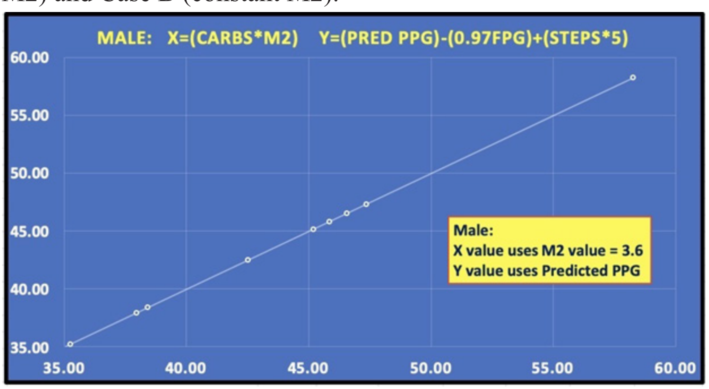


Figure 2-1: (Part 2) Male case using fixed M2 value of 3.6 (1/18/2020 - 10/18/2020)

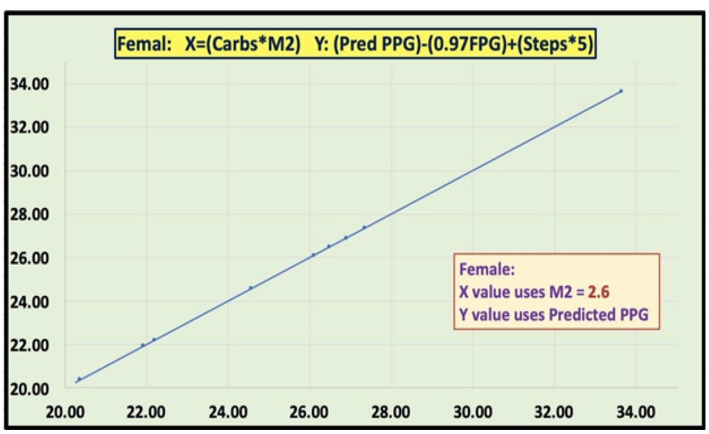


Figure 2-2: (Part 2) Female case using fixed M2 value of 2.6 (1/18/2020 - 10/18/2020)

Figure 1 depicts the results from using variable M2 values to achieve a 100% match between the predicted PPG and measured PPG of each year.

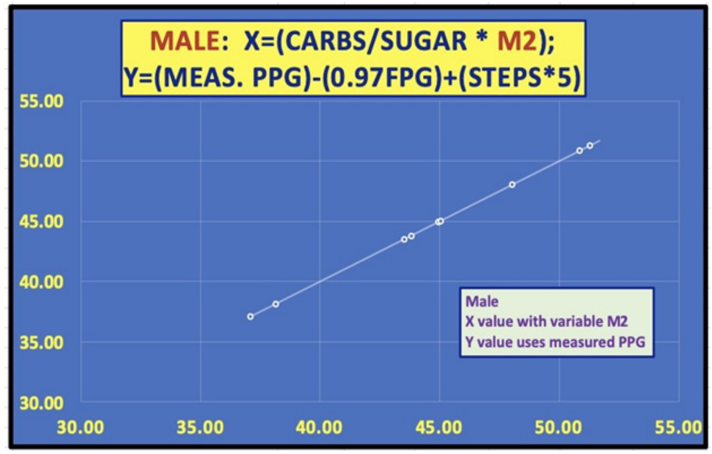


Figure 2-3: (Part 2) Male case using variable M2 values (1/18/2020 - 10/18/2020)

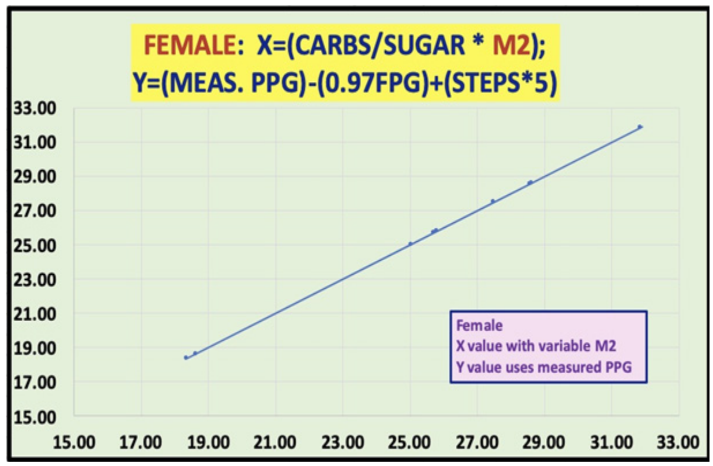


Figure 2-4: (Part 2) Female case using variable M2 values (1/18/2020 - 10/18/2020)

Listed below are the values for the variable 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
Average - 1.82

In Figure 2, 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%
Average - 100%

In fact, the prediction accuracies varying between 93% to 103% with a 6-year average 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 3 illustrates 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.

From Figure 4, it is obvious that the six-annual data "almost" form a straight line with a slope of 45% between carbs and PPG delta. The author calls the linear phenomenon and data points having small deviations from the line as a "pseudo-linear" relationship. This is similar to the "elastic zone" of the Stress-Strain-Young's modulus diagram in theory of elasticity and strength of materials of structural and mechanical engineering (Figure 1). This linear relationship makes the task of incremental PPG prediction through diabetes control via diet much easier.

Part 2
Fixed & Variable M2 of two Patients

Fixed M2 Case

In Part 2, the author utilized two different fixed values of M2 for Case A and Case B, respectively to calculate both x- and y- components of his *"linear elastic glucose" equation. The comparison between Case A's M2 value of 3.6 and Case B's M2 of 2.6 revealed the individual severity of their respective T2D conditions.* Case A indicates a more severe diabetes patient who requires higher M2 (or GH modulus) 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 5 and 6 demonstrate two different fixed M2 values and corresponding data ranges for Case A and Case B, respectively.

Case A 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 5. Case B 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 Figure 6.

In summary, the higher the M2, the higher x and y values become, and the higher predicted and measured PPG values are. The key point is that the monthly M2 values (i.e. GH-modulus) are dependent on the patient's body conditions (a combination of blood, liver, and pancreas) of that particular month.

Listed below are the values of the prediction accuracy for Case A and Case B 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 cases which is the purpose of selecting these two fixed M2 values. However, this approach will cause some degree of sacrifice on monthly PPG prediction's accuracy for each month. It should be noted that the prediction accuracy range are 88%-111% and 93%-108% for Case A and Case B, 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

In this section, 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 the pancreatic beta cells' self-repair process is extremely 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 monthly sub-periods. This would be a reasonable approach in proceeding with this biomedical research.

In the previous paragraph, the fixed M2 difference between Case A of 3.6 versus Case B 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, Case A has M2 range from 2.8 to 5.2 with an average of 3.7 value (Figure 5), and Case B has M2 range from 1.9 to 3.6 with an average of 2.7 value (Figure 6). 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 Case A with variable M2, both x and y components are within the range of 37 to 51 with an average value of 45. For Case B 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 the 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, a combination of blood, liver, and pancreas, for that particular month.

Figures 7 and 8 have graphically demonstrated the linear elastic glucoses data for Case A and Case B, respectively.

Listed below are the values of the individual M2 multiplier (i.e., variable GH-modulus) for each month in 2020, in the order of Case A vs. Case B:

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 cases.

Part 3
Variable M2 of three Patients

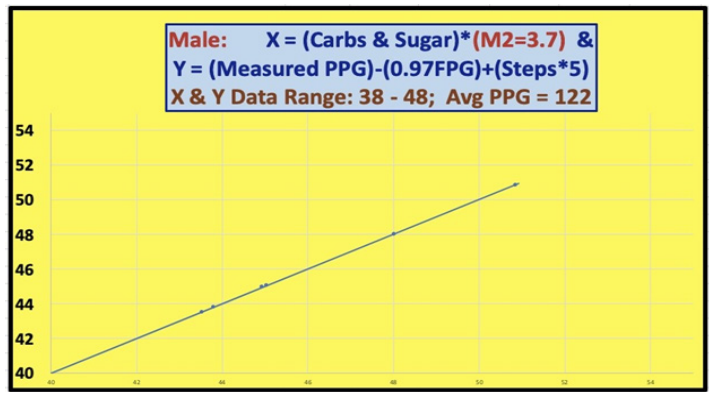


Figure 3-1: (Part 3) Linear elastic glucose behavior between carbs/sugar input and incremental PPG output for ***male case A*** during the 7-month period

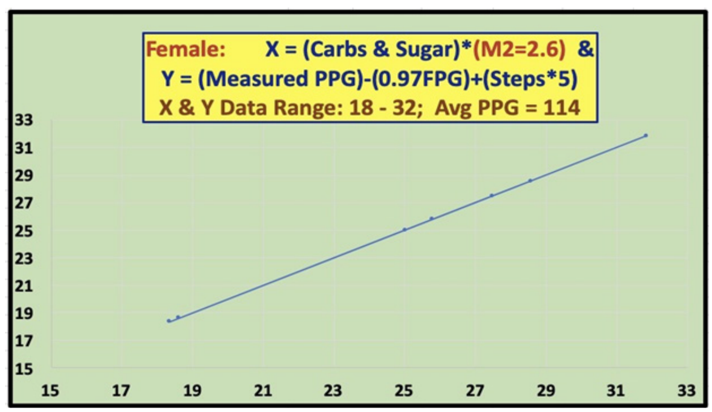


Figure 3-2: (Part 3) Linear elastic glucose behavior between carbs/sugar input and incremental PPG output for ***female case B*** during the 7-month period

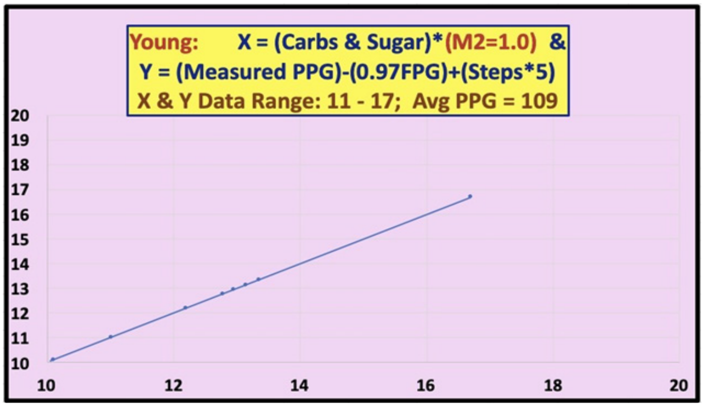


Figure 3-3: (Part 3) Linear elastic glucose behavior between carbs/sugar input and incremental PPG output for ***young case C*** during the 7-month period

Due to the high accuracy of predicted PPG, as mentioned above, there are some insignificant rounding-off errors between the predicted PPG values and measured PPG values. Therefore, he decided to use the measured PPG values in these three cases.

Here is the calculated x- and y- components as follows:

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

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, and 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 9. 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 10. 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 11.

In summary, the 7-month average values 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. 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, especially their diabetes severity (i.e. blood, liver, and pancreas). This is similar to the different inorganic engineering materials with the different Young's modules values, such as nylon ~3 versus steel ~200.

Discussion

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. After experiencing five cardiovascular episodes, with an average glucose value of 280 mg/dL and HbA1C of 10%, he started to self-study and research diabetes and food nutrition in 2010. 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 (average glucose 116 mg/dL with some peaks). This also suggests that his PPG would land in a reasonable range (around 120 mg/dL or below) when he consumes lesser amounts of carbs/sugar and exercising adequately.

On the other hand, during the period of 2000-2010 (it could even extend to 2013), when his diabetes was totally out of control, he believes that his case should belong 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 having "elevated glucoses" or hyperglycemia >180 mg/dL, he could suffer from hypoglycemia with 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 2013 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 the larger area of nonlinear plastic period of 2010-2013. 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 published research papers starting in 2019, he has proven that his pancreatic beta cells' insulin capability of production and quality have been self-repairing 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, whereas 27% have been repaired since 2011 which covers both partial plastic zone and elastic zone. This type of "organic" cells' regeneration capability and biomedical phenomena was unknown to him when he was an engineer dealing only with variety of "inorganic" materials, such as metal, concrete, and silicon. As a result, since 2010, he has been fascinated in working with the various stimulators and complex stimulations of the biomedical system. The more research work he performs, the more unknown phenomena occur, and the more questions enter his mind, causing him to search for more and better solutions.

Part 2
Two Patients

This "linear elastic glucose" study has 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 maintaining the basic requirement of science that is to seek for truth with high precision.

By 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 in using both approaches.

One important viewpoint is that glucose is an organic biomedical material, which consists of both 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. Currently, he lacks the needed and sufficient data to conduct his research; however, similar to the linear elasticity engineering applications, this linear elastic glucose behavior study already covers a sufficient scope of biomedical applications which remains to be 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 hyperglycemic range (i.e., glucose at 180 mg/dL or lower). This simpler "linear glucose model" can be extremely useful for many diabetes patients worldwide. 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.

Part 3
Three Patients

In this part, the author has 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 organic cells system is a 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. 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.

Conclusions

Here are the main conclusions of this article:
First, by using an analogy from the theory of elasticity and engineering strength of material, the author has identified a linear relationship existing between carbs and PPG delta with a newly defined GH-modulus, similar to a linear relationship between stress and strain with Young's modulus.

Second, based on two diabetes patients' 9-month data, he has proven that the magnitude of GH-modulus is directly proportional to the diabetes severity of the patients.

Third, by utilizing three diabetes patients' 7-month data, he has confirmed that the magnitude of the monthly GH-modulus is directly proportional to the diabetes severity of that particular month for each patient.

Fourth, these linear elastic glucose behavior findings are probably applicable to a glucose range from 70 mg/dL to 180 mg/dL which covers most situations for a diabetes patient. For glucose values falling outside the range, a nonlinear plastic glucose behavior study is needed [1-9]..

Acknowledgement

Foremost, I would like to express my deep appreciation to my former professors: professor James Andrews at the University of Iowa, who helped develop my foundation in basic engineering and computer science, and professor Norman Jones at the Massachusetts Institute of Technology, who taught me how to solve tough scientific problem through the right attitude and methodology.

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