Special Issue 5
2022

https://www.theghmethod.com

The GH-Method

Viscoelastic or Viscoplastic Glucose Theory (VGT #68): A Study of Postprandial Plasma Glucose versus Carbohydrates & Sugar Intake Grams and Daily Walking Steps Using a Customized Software Program and VGT Energy Tool from Physics and Engineering Based on GH-Method: Math-Physical Medicine (No. 657)

Gerald C. Hsu*

eclaireMD Foundation, USA

Keywords: Viscoelastic; Viscoplastic; Postprandial plasma glucose; Type 2 diabetes; Carbohydrates; Sugar; Daily walking steps; Fasting plasma glucose

Abbreviations: T2D: type 2 diabetes; SD: space domain; TD: time domain; PPG: postprandial plasma glucose; FPG: fasting plasma glucose; MPM: math-physical medicine

1. INTRODUCTION

The author has been a type 2 diabetes (T2D) patient since 1995. He studied and researched blood sugar (glucose) starting in 2012 and post-meal glucose or postprandial plasma glucose (PPG) since 2014. In 2017, he applied a signal processing technique from physics and electronics engineering to decompose a PPG waveform (curve) into 19 components with 19 different sub-waveforms. Among these 19 influential factors for PPG formation, carbohydrates and sugar intake amount from food (carbs/sugar) and post-meal exercise of walking steps (steps) are the two most prominent influential factors. In 2021, after reading a few physiology and pathology textbooks, he has learned that there are 8 pathways to induce or trigger various chronicle diseases, including the most common 3 types of T2D, high blood pressure (hypertension), and unhealthy blood lipids of HDL, LDL, and triglycerides (hyperlipidemia). Diet connects with the 8 bio-pathways while exercise connects with 5 out of the 8 pathways. In other words, if considering these two prominent factors alone, diet contributes 60% and exercise contributes 40% of PPG, the major component of diabetes. A summarized statement can be stated: "any type or amount of exercise cannot outrun a bad diet".

He has further learned from his 13 years of food nutrition study that he should avoid any kind of processed food prepared by machine or factory. Therefore, naturally grown plant-based vegetables and fruits are the best choices for his diet preparation.

The author's stringent lifestyle management efforts, including both diet and exercise, are directly beneficial to his weight reduction, glucose control, and metabolism improvements. At this point, it is necessary to briefly describe his health history.

The author was diagnosed with T2D in 1997 with a random glucose check at a 300 mg/dL level; however, his T2D condition most likely began earlier (he guesses 1995). He suffered his first two chest pain episodes in 1993-1994 and three more heart episodes until 2007. His primary physician informed him that he had diabetic kidney issues in 2010. He then consulted with two more clinical doctors who advised him to immediately start insulin injections and kidney dialysis. This was his wake-up call. He then decided to save his own life by conducting his study and research on

Available online: 30 July 2022

*Corresponding author: Gerald C. Hsu, eclaireMD Foundation, USA

food nutrition and chronic diseases that same year. His health profile in 2010 was: body weight at 220 lbs. (BMI 32), average glucose at 280 mg/dL, fasting plasma glucose (FPG) in the early morning at 180 mg/dL, lab-tested HbA1C at 10%, triglycerides at 1160 mg/dL (target: <150 mg/dL), and his ACR at 116 (target: <30). In summary, by 2010, he has also suffered a total of 5 heart episodes, chronic kidney diseases, foot ulcers, hypothyroidism, diabetic retinopathy, etc.

Over the past ~13 years, he has made significant lifestyle changes. For example, he consumes less than 15 grams of carbohydrates and sugar per meal, avoids processed food, reduces his food quantity by 50%, and walks 6-7 miles or 10-11 kilometers daily (his target is at least 9,000 steps each day), sleeps 7-8 hours each night, and reduces stress as much as possible. In addition, he has never drunk alcohol, smoked cigarettes, or used any illicit drugs in his life.

As of April 25, 2022, his health profile for the first 4 months of 2022 was: body weight at 169 lbs. (BMI 24.95), daily average glucose at 106 mg/dL, FPG in the early morning at 94 mg/dL, lab-tested A1C at 5.8%, triglycerides at 108, and ACR at 16. A significant accomplishment is that he has discontinued taking 3 different kinds of diabetes medications since 12/8/2015.

Regarding the dataset used, the author has started to keep detailed data on his diet and exercise and other biomarkers since 5/1/2015. Therefore, this study of PPG versus carbs/sugar and walking steps using the viscoelastic/plastic method is based on his collected data for nearly 7 years from 5/1/2015 to 4/25/2022.

Recently, the author has modified his software on the iPhone to include the capability of calculating the strain (ε) change rate, i.e. dε/dt, and then be able to multiply with a selected viscosity factor (η). With this enhanced feature embedded in his software program, he can then avoid using the Excel program on the PC to conduct the needed VGT analysis. Now, he can conduct multiple VGT analyses based on thousands of daily data on the iPhone, instead of under the restriction of using "period data", such as annual, quarterly, or monthly, on Excel which requires significant data preparation time.

Most of the author's medical papers are based on his collected biomarker data from his own body over the past 12+ years. His research work is based on quantitative analysis of the collected data using a math-physical medicine methodology, not like using the traditional biochemical and statistical research approach in the current medical research arena. In other words, he describes his observed biophysical phenomena using 10 numerical digits mainly instead of the traditional biochemical phenomena using 26 English alphabets. This is due to his lack of training in both biology and chemistry. Based on his past 13-year of self-study and intensive research on internal medicine and food nutrition, he has observed that most biomedical phenomena do follow the basic law of physics. Therefore, certain principles and modeling techniques of engineering can be applied easily in medical research. Under this situation, it can then be easily analyzed and interpreted using various mathematical tools from the foundation level and using various engineering modeling techniques from the application level, with physics situated in the middle layer.

2. METHODS

To offer a simple explanation to readers who do not have a physics or engineering background, the author includes a brief excerpt from Wikipedia regarding the description of basic concepts for elasticity and plasticity theories, viscoelasticity, and viscoplasticity theories from the disciplines of engineering and physics in this method section.

2.1 Relationships between biomedical causes and biomedical symptoms

As a mathematician/engineer over 40 years and now conducting his medical research work for the past 13 years, the author has discovered that people frequently seek answers, illustrations, or explanations for the relationships between the input variable (force applied on a structure or cause of a disease) and output variable (deformation of a structure or symptom of a disease). However, the multiple relationships between input and output could be expressed with many different matrix formats of 1 x 1, 1 x n, m x 1, or m x n (m or n means different multiple variables). In addition to these described mathematical complications, the output resulting from one or more inputs can also become an input of another output, which is a symptom of certain causes that can become a cause of another different symptom. This phenomenon is indeed a complex scenario with "chain effects". In fact, both engineering and biomedical complications are fundamentally mathematical problems that correlate or conform with many inherent physical laws or principles. In his medical research work, he has encountered more than 100 different sets of biomarkers with almost equal or more amounts of causes (or input variables) and symptoms (or output variables).

Since December of 2021, the author applied theories of viscoelasticity and viscoplasticity (VGT) from physics and engineering disciplines to investigate more than 60 sets of input/output biomarkers, including nearly 10 sets of cancer cases. The purpose is to identify certain hidden relationships between certain output biomarkers, such as cancer risk, and its corresponding multiple inputs, such as glucose, blood pressure, blood lipids, obesity or overweight, and metabolism index of 6 lifestyle details and 4 chronic diseases. In this study, the hidden biophysical behaviors and possible inter-relationships among the output symptom and multiple input causes are "time-dependent" and change from time to time. These important time-dependency characteristics provide insight into the cancer risk's moving pattern. It also controls the cancer risk curve shape, the associated energy created, stored, or burned inside during the process of stress up-loading (moving upward or increasing) and stress down-loading (moving downward or decreasing) of the input biomarkers with the output biomarker of cancer risk %. This VGT application emphasizes the time-dependency characteristics of involved variables. In the medical field, most biomarkers are time-dependent since body organ cells are organic in nature and change all of the time. Incidentally, VGT can generate a stress-strain curve or cause-symptom curve, known as a "hysteresis loop" in physics, in which area size can also be used to estimate the relative energy created, stored, or burned during the process of uploading (e.g., increasing glucose) and unloading (e.g., decreasing body weight) over the timespan of the cancer risk %. He calls this relative energy the "VGT energy".

It should be emphasized here that both cancer risk % and its associated VGT energy are estimated relative values, not "absolute" values.

The following defined stress and strain equations are used to establish the VGT stress-strain diagram in a space domain (SD):

VGT strain
= ε (symptom)
= individual symptom at the present time

VGT stress
= σ (based on the change rate of strain, symptom, multiplying with one or more viscosity factors or influential factors)
= η * $(d\varepsilon/dt)$
= η * (d-strain/d-time)
= (viscosity factor η using normalized factor at present time) * (symptom at present time - symptom at a previous time)

Where the strain is the cancer risk percentage and the stress is his cancer risk change rate multiplied by several chosen input biomarkers as the individual viscosity factor. In his VGT studies, sometimes, he carefully selects certain normalization factors for each input biomarker, respectively. The normalization factors are the dividing lines between a healthy state and an unhealthy state. For example, 170 lbs. for body weight, 6.0 for HbA1C, 120 mg/dL for glucose, 180 mg/dL for hyperglycemia, 73.5% for overall MI score, and 10,000 steps for daily walking exercise, etc.

2.2 Elasticity, plasticity, viscoelasticity, and viscoplasticity (LEGT & VGT)

The difference between elastic materials and viscoelastic materials (from "Soborthans, innovating shock and vibration solutions").

What are elastic materials?

Elasticity is the tendency of solid materials to return to their original shape after forces are applied on them. When the forces are removed, the object will return to its initial shape and size if the material is elastic.

Medical analogy: The medical application is when cause or risk factors are reduced or removed, the symptoms of certain disease would be improved or ceased.

What are viscous materials?

Viscosity is a measure of a fluid's resistance to flow. A fluid with large viscosity resists motion. A fluid with low viscosity flows. For example, water flows more easily than syrup because it has a lower viscosity. High viscosity materials might include honey, syrups, or gels – generally things that resist flow. Water is a low viscosity material, as it flows readily. Viscous materials are thick or sticky or adhesive. Since heating reduces viscosity, these materials don't flow easily. For example, warm syrup flows more easily than cold.

What is viscoelastic?

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Synthetic polymers, wood, and human tissue, as well as metals at high temperature, display significant viscoelastic effects. In some applications, even a small viscoelastic response can be significant.

Medical analogy: Viscoelastic behavior means material has "time-dependent" characters. Biomedical data, i.e. biomarkers, are time-dependent due to body cells are organic which changes with time constantly.

Elastic behavior versus viscoelastic behavior

The difference between elastic materials and viscoelastic materials is that viscoelastic materials have a viscosity factor and the elastic ones don't. Because viscoelastic materials have the viscosity factor, they have a strain rate dependent on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed; however, a viscoelastic substance does.

Medical analogy: Most of the biomarkers display time-dependency; therefore they have both change-rate of time and viscosity factor behaviors. Viscoelastic biomarkers do dissipate energy when a cause force is applied on it.

The following brief introductions are excerpts from Wikipedia:

"Elasticity (physics):

The physical property is when materials or objects return to their original shape after deformation.

In physics and materials science, elasticity is the ability of a body to resist a distorting influence and to return to its original size and shape when that influence or force is removed. Solid objects will deform when adequate loads are applied to them; if the material is elastic, the object will return to its initial shape and size after removal. This is in contrast to plasticity, in which the object fails to do so and instead remains in its deformed state.

Hooke's law states that the force required to deform elastic objects should be directly proportional to the distance of deformation, regardless of how large that distance becomes. This is known as perfect elasticity, in which a given object will return to its original shape no matter how strongly it is deformed. This is an ideal concept only; most materials that possess elasticity in practice remain purely elastic only up to very small deformations, after which plastic (permanent) deformation occurs.

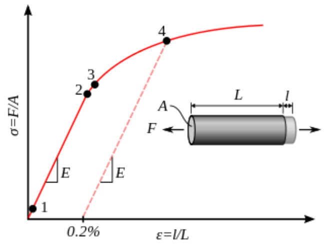
In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic limit or yield strength is the maximum stress that can arise before the onset of plastic deformation.

Medical analogy: The elastic behavior analogy in medicine can be expressed by the metal rod analogy for the postprandial plasma glucose (PPG). Consuming carbohydrates and/or sugar acts like a tensile force to stretch a metal rod longer, while post-meal exercise acts like a compressive force to suppress a metal rod shorter. If lacking food consumption and exercise, the metal rod (analogy of PPG) will remain its original length, for a non-diabetes or less severe type 2 diabetes (T2D) patient.

Plasticity (physics):

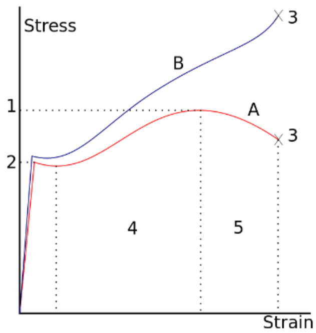
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

In physics and materials science, plasticity, also known as plastic deformation, is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces. For example, a solid piece of metal being bent or pounded into a new shape displays plasticity as permanent changes occur within the material itself. In engineering, the transition from elastic behavior to plastic behavior is known as yielding. Plastic deformation is observed in most materials, particularly metals, soils, rocks, concrete, and foams.



A stress-strain curve showing typical yield behavior for nonferrous alloys.

1. True elastic limit
2. Proportionality limit
3. Elastic limit
4. Offset yield strength



A stress-strain curve typical of structural steel.

- 1: Ultimate strength
- 2: Yield strength (yield point)
- 3: Rupture
- 4: Strain hardening region
- 5: Necking region
- A: Apparent stress (F/A0)
- B: Actual stress (F/A)

For many ductile metals, tensile loading applied to a sample will cause it to behave in an elastic manner. Each increment of load is accompanied by a proportional increment in extension. When the load is removed, the piece returns to its original size. However, once the load exceeds a threshold – the yield strength – the extension increases more rapidly than in the elastic region; now when the load is removed, some degree of extension will remain.

Medical analogy: A plastic behavior analogy in medicine is the PPG level of a severe T2D patient. Even consuming a smaller amount of carbs/sugar, the patient's PPG will rise sharply which cannot be totally brought down to a healthy PPG level even with a significant amount of exercise. This means the PPG level has exceeded its "elastic limit" and entering into a "plastic range".

Viscoelasticity:

Property of materials with both viscous and elastic characteristics under deformation.

In materials science and continuum mechanics, viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like water, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed.

Viscoelastic materials have elements of both of these properties and, as such, exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.

In the nineteenth century, physicists such as Maxwell, Boltzmann, and Kelvin researched and experimented with creep and recovery of glasses, metals, and rubbers. Viscoelasticity was further examined in the late twentieth century when synthetic polymers were engineered and used in a variety of applications. Viscoelasticity calculations depend heavily on the viscosity variable, η. The inverse of η is also known as fluidity, φ. The value of either can be derived as a function of temperature or as a given value (i.e. for a dashpot).

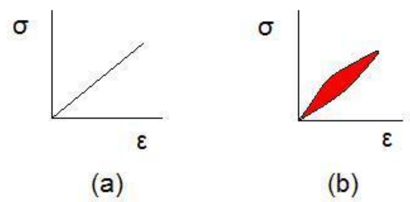
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit rubber-like behaviors explained by the thermodynamic theory of polymer elasticity.

Cracking occurs when the strain is applied quickly and outside of the elastic limit. Ligaments and tendons are viscoelastic, so the extent of the potential damage to them depends both on the rate of the change of their length as well as on the force applied.

A viscoelastic material has the following properties:

- hysteresis is seen in the stress-strain curve
- stress relaxation occurs: step constant strain causes decreasing stress
- creep occurs: step constant stress causes increasing strain
- its stiffness depends on the strain rate or the stress rate.

Elastic versus viscoelastic behavior:



Stress-strain curves for a purely elastic material (a) and a viscoelastic material (b). The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle. It is equal to $\oint \sigma d\varepsilon$ where σ is stress and ε is strain. In other words, the hysteresis loop area represents the amount of energy during the loading and unloading process.

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. The viscosity of a viscoelastic substance gives the substance a strain rate dependence on time. Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed. However, a viscoelastic substance dissipates energy when a load is applied, then removed. Hysteresis is observed in the stress-strain curve, with the area of the loop being equal to the energy lost during the loading cycle. Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. Plastic deformation results in lost energy, which is uncharacteristic of a purely elastic material's reaction to a loading cycle.

Viscoplasticity:

Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied. The inelastic behavior that is the subject of viscoplasticity is plastic deformation which means that the material undergoes unrecoverable deformations when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load.

Medical analogy: In viscoelastic or viscoplastic analysis, the stress component equals the strain change rate of time multiplying with the viscosity factor, or

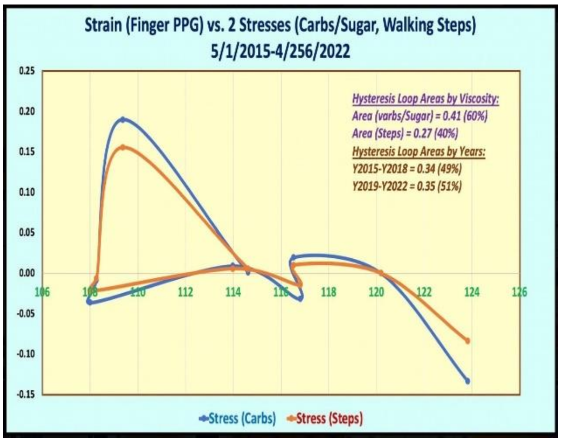
Stress (σ)
= strain (ε) change rate * viscosity factor (η)
= $d\varepsilon/dt * \eta$

The hysteresis loop area
= the integrated area of stress (σ) and strain (ε) curve
= $\oint \sigma d\varepsilon$

Note: For a more detailed description, please refer to the "consolidated method" section which is given at the beginning of the special issue.

3. RESULTS

Figure 1 shows the stress-strain diagrams of PPG versus both carbs/sugar amount and daily walking steps with a supporting data table.



4/26/22	Strain	Strain Rate * eta	Strain Rate	Viscosity	Carbs/15
5/1/15-4/25/22	PPG	PPG Rate * Carbs	PPG change rate	Carbs/sugar	Norm. Carbs
Y2015	124	-0.13	-0.14	14.28	0.95
Y2016	120	0.00	0.00	15.55	1.04
Y2017	117	0.02	0.02	14.52	0.97
Y2018	117	-0.03	-0.03	15.82	1.05
Y2019	114	0.01	0.01	13.24	0.88
Y2020	108	-0.04	-0.04	13.68	0.91
Y2021	108	-0.01	-0.01	12.77	0.85
Y2022	109	0.19	0.25	11.40	0.76
Average	115	0.00	0.01	13.91	0.93

4/26/22	Strain	Strain Rate * eta	Strain Rate	Viscosity	9000/steps
5/1/15-4/25/22	PPG	PPG Rate * Steps	PPG Rate	Steps	Norm. Steps
Y2015	124	-0.08	-0.14	14997	0.60
Y2016	120	0.00	0.00	17017	0.53
Y2017	117	0.01	0.02	17863	0.50
Y2018	117	-0.01	-0.03	18458	0.49
Y2019	114	0.01	0.01	15742	0.57
Y2020	108	-0.02	-0.04	16256	0.55
Y2021	108	-0.01	-0.01	14566	0.62
Y2022	109	0.16	0.25	14471	0.62
Average	115	0.01	0.01	16171	0.56

4/26/22	Strain	Strain Rate * eta	Strain Rate * eta				
5/1/15-4/25/22	PPG	Stress (Carbs)	Stress (Steps)	Area (Carbs)	Area (Steps)	Total Area	Area %
Y2015	124	-0.13	-0.08	0	0		
Y2016	120	0.00	0.00	0.24	0.15		
Y2017	117	0.02	0.01	-0.04	-0.02		
Y2018	117	-0.03	-0.01	0.00	0.00	0.34	49%
Y2019	114	0.01	0.01	0.03	0.01		
Y2020	108	-0.04	-0.02	0.08	0.05		
Y2021	108	-0.01	-0.01	-0.01	0.00		
Y2022	109	0.19	0.16	0.10	0.08	0.35	51%
Average / Sum	115	0.00	0.01	0.41	0.27	0.69	
				60%	40%	100%	100%

Figure 1: Stress-strain diagram of PPG versus carbs/sugar amount and daily walking steps with supporting data table.

4. CONCLUSION

The following four described biophysical characteristics have demonstrated behaviors of PPG under 2 chosen influential factors of carbs/sugar and daily walking steps (a 2x1 model) with the viscoelastic or viscoplastic energy (VGT) tool:

(1) From the x-axis value or the strain value on the stress-strain diagram, the 8-year PPG values cover a range from the high-end of 124 mg/dL in Y2015 to the low-end of 109 mg/dL in Y2021 with a decreasing trend in between. Except for his PPG level, it has risen to 115 mg/dL during the first 4 months of 2022. Hopefully, by end of 2022, the PPG level will be maintained at a lower level again.

(2) From his two chosen viscosity values, his average carbs/sugar is 13.91 mg/dL which is lower than his target of 15 mg/dL (his diet normalization level) and his average daily walking steps is 16,171 steps which are higher than his target of 9,000 steps (his exercise normalization level).

(3) The performance beyond targets of both diet and exercise has helped the y-axis (stress) values and their associated hysteresis loop areas. In combining these two viscosity values (carbs/sugar and walking steps) and strain rates, which is the PPG change amount over time, he can produce two respective stress values. The two stress-strain curves can then be constructed. From this stress-strain diagram, we can observe that there are two distinct shapes of hysteresis loops associated with a period of Y2015-Y2018 versus the period of Y2019-Y2022.

(4) When we delve deeper into the hysteresis loop area comparison between the two influential factors, we can observe that "carbs/sugar contributes 60% and walking contributes 40% of PPG".

In summary, this unique "time-dependency" characteristic of strain change rate, PPG change amount over time, can be applied to glucose research and discover useful findings. Incidentally, this math-physical medicine research finding of 60% vs. 40% matches with the physiopathological finding of 8 vs. 5.

This report on PPG versus carbs/sugar and walking steps has demonstrated how the author utilizes the mathematics, physics, and engineering, VGT energy methodology, to construct and display his research results on PPG resulting from two prominent influential factors, carbs/sugar intake amount and daily walking steps.

5. REFERENCES

For editing purposes, the majority of the references in this paper, which are self-references, have been removed. Only references from other authors' published sources remain. The bibliography of the author's original self-references can be viewed at www.eclairemd.com.

Special Issue | Issue No. 5

The GH-Method

Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

Gerald C. Hsu

https://theghmethod.com

2022