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Viscoelastic or Viscoplastic Glucose Theory (VGT #78): A Sensitivity Analysis of the Baseline Selection for Normalized Fasting Plasma Glucose to Study Two Symptoms of Postprandial Plasma Glucose and Glucose Fluctuation Versus 3 Causes of FPG, Carbohydrates/Sugar Grams, and Post-Meal Walking Steps Based on GH-Method: Math-Physical Medicine and the Utilization of the VGT Energy Tool (No. 668)

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Abstract

The author has applied viscoelastic and viscoplastic theories (VGT) to conduct 77 different sets of studies regarding symptoms (strains ε) versus multiple causes (stresses σ) in the biomedical field beginning with paper No. 578 on 1/8/2022.

In this article, he used 7,330 data of postprandial plasma glucose (PPG), glucose fluctuation (GF) along with their related data, such as fasting plasma glucose (FPG), carbohydrates/sugar intake amounts (carbs), and post-meal walking steps (steps). The collected data is from a continuous glucose monitoring (CGM) sensor device over 4 years from 5/8/2018 to 5/13/2022.

He utilizes the following defined VGT equation from engineering and physics to address the "time-dependency characteristic" of biomedical symptoms and their causes to establish several stress-strain diagrams (i.e. cause-symptom diagrams) in a space domain (SD) via various hysteresis loops:

strain
= ε (PPG or GF)
= individual GF value at the present time

Stress
= σ (based on the change rate of strain, PPG rate, or GF rate, multiplying with a chosen viscosity factor η, FPG, carbs, or steps)
*= η * (dε/dt)*
*= η * (d-strain/d-time)*
*= (viscosity factor η using individual FPG, carbs, or steps at present time) * (PPG or GF at present time - PPG or GF at a previous time)*

He defines GF as the maximum PPG minus the minimum PPG value.

The 3 causes or 3 viscosity factors are further grouped into two different categories, where the first category is not used in this paper:

First Category:
Non-modified original data from various measurements

FPG = an average glucose value over 7 hours of sleep time
Carbs = estimated carbs/sugar intake grams for each meal
Steps = recorded post-meal walking steps divided by 1,000 for each meal

Second Category:
Normalized data based on dividing lines between healthy vs. unhealthy

Normalized FPG = average FPG / X (X mg/dL is the dividing line between normal and diabetes, X<99 mg/dL is normal, 100<X<120 mg/dL is pre-diabetes, >120 mg/dL is type 2 diabetes)

Normalized carbs = average carbs / 15 (15 grams of carbs/sugar is the target for his severe T2D conditions)

Normalized steps = 4.0 / k-steps (4,000 post-meal walking steps is his target to keep his PPG in control).

Papers No. 666 (PPG vs. FPG, carbs, and steps) and No. 667 (GF vs. FPG, carbs, and steps) utilized 120 mg/dL as the baseline value of normalized FPG. However, in this article, he uses 99 mg/dL as the baseline value of normalized FPG for a sensitivity study against the findings from the previous two papers using 120 mg/dL as the baseline of normalized FPG.

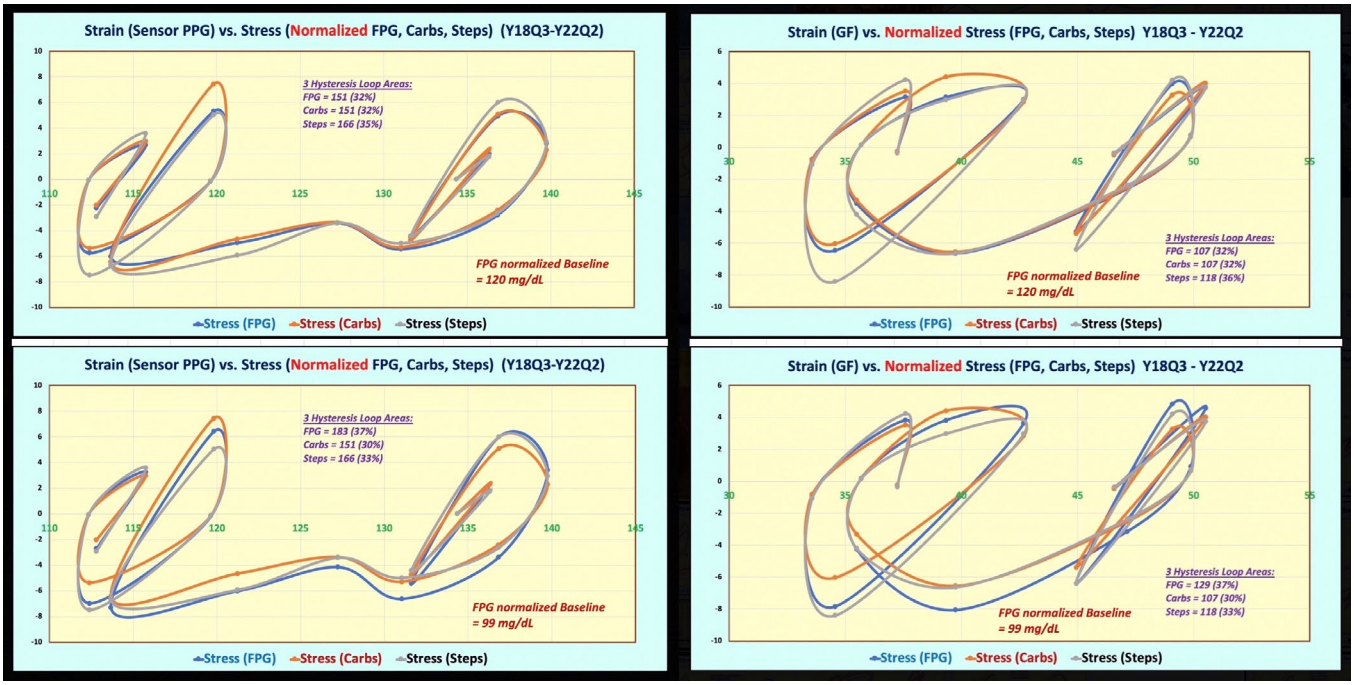
In summary, there are 4 key findings from this sensitivity study using FPG as an example:

*From the FPG viewpoint, the general definition of diabetes status (i.e. baseline value for normalized FPG values) is Normal if FPG is lower than 99 mg/dL, Pre-diabetes if FPG is between 100 mg/dL and 120 mg/dL, Diabetes if FPG higher than 120 mg/dL. The normalized FPG is equal to the FPG value divided by the baseline value of 120 or 99; therefore, a higher baseline value would make the normalized FPG value smaller. A smaller normalized FPG (i.e. viscosity factors η) would make the corresponding stress value lower since the stress σ = strain rate (d-PPG/dt or d-GF/dt) * viscosity factor (η or FPG). Given the same strain rate, a smaller stress value would make the hysteresis loop area smaller since the hysteresis loop area = (strain rate) * (present stress + previous stress)/2.*
For a pre-diabetes case of 120 mg/dL, the related hysteresis loop area of FPG is smaller which results in a more evenly distributed pattern of hysteresis loop area (i.e. energy or degree of influence) with FPG=32%, carbs=32%, and steps=36%. The steps contribution is the highest.

For a normal condition case of 99 mg/dL, the related hysteresis loop area of FPG is larger which results in a more skewed distribution pattern of hysteresis loop area (i.e. energy or degree of influence) with FPG=37%, carbs=30%, and steps=33%. The FPG contribution is the highest.

Under a future hypothetical situation, if the author continues to improve his FPG conditions or lower FPG values via self-repairing of his damaged pancreatic beta cells, then eventually the contribution % of his stress and hysteresis loop area associated with FPG will also be lowered, and eventually reach a similar level as carbs and steps (i.e. 33%: 33%: 33%).

These dimensionless variables, i.e. normalized viscosity factors, actually offer a clear picture regarding the division of medical conditions between healthy versus unhealthy. This particular example of FPG is quantitative proof of the sensitivity of baseline value for the normalization process.



Introduction

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Method

MPM Background

To learn more about his developed GH-Method: math-physical medicine or MPM methodology, readers can select the following three articles from the 400+ published medical papers.

The first paper, No. 386, describes his MPM methodology in a general conceptual format. The second paper, No. 387, outlines his personalized diabetes research history, various application tools, and the differences between the biochemical medicine (BCM) approach versus the MPM approach. The third paper, No. 397, depicts a general flow diagram containing ~10 key MPM research methods and different tools.

All of the listed papers in the Reference section are his written and published medical research papers.

The Author's Case of Diabetes

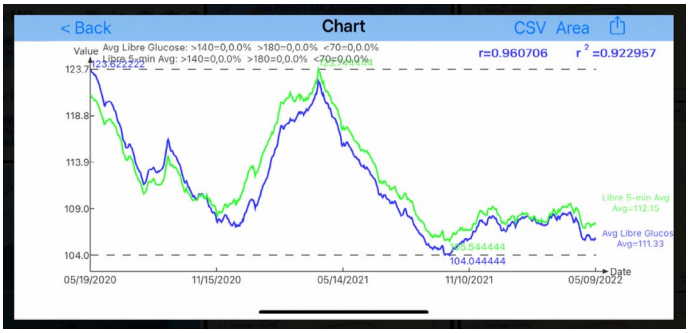
The author has been a severe T2D patient since 1996. He weighed 220 lb. (100 kg, BMI 32.5) at that time. By 2010, he still weighed 198 lb. (BMI 29.2) with average daily glucose of 250 mg/dL (HbA1C of 10%). During that year, his triglycerides reached 1161 and albumin-creatinine ratio (ACR) at 116. He also suffered from five cardiac episodes within a decade. In 2010, three independent physicians warned him about his need for kidney dialysis treatment and his future high risk of dying from severe diabetic complications. Other than the cerebrovascular disease (stroke), he has suffered the most known diabetic complications, including macrovascular and microvascular complications.

In 2010, he decided to launch his self-study on endocrinology, diabetes, and food nutrition to save his own life. During 2015 and 2016, he developed four prediction models related to diabetes conditions: weight, PPG, fasting plasma glucose (FPG), and A1C. As a result, from using his developed mathematical metabolism index (MI) model in 2014 and the four prediction tools, by end of 2016, his weight was reduced from 220 lbs. (100 kg, BMI 32.5) to 176 lbs. (89 kg, BMI 26.0), waistline from 44 inches (112 cm) to 33 inches (84 cm), average finger glucose reading from 250 mg/dL to 120 mg/dL, and lab-tested A1C from 10% to ~6.5%. *One of his major accomplishments is that he no longer takes any diabetes medications as of 12/8/2015.*

In 2017, he has achieved excellent results on all fronts, especially glucose control. However, during the pre-COVID period of 2018 and 2019, he traveled to approximately 50+ international cities to attend 65+ medical conferences and made ~120 oral presentations. This hectic schedule inflicted damage to his diabetes control, through dining out frequently, post-meal exercise disruption, jet lag, and along with the overall metabolic impact due to his irregular life patterns through a busy travel schedule; therefore, his glucose control and overall metabolism state were somewhat affected during this two-year heavier traveling period.

Since 2020, living in a COVID-19 quarantined lifestyle, not only has he published 400+ medical papers in 100+ journals, but he has also reached his best health conditions in the past 26 years. By the beginning of 2022, his weight was further reduced to *168 lbs. (BMI 24.8) along with a 5.8% A1C value (beginning level of pre-diabetes),* without having any medication interventions or insulin injections. These good results are due to his non-traveling, low-stress, and regular daily life routines. Of course, his knowledge of chronic diseases, practical lifestyle management experiences, and development of various high-tech tools contribute to his excellent health status since 1/19/2020, the beginning date of his self-quarantined life.

On 5/5/2018, he applied a continuous glucose monitoring (CGM) sensor device on his upper arm and checks his glucose measurements every 5 minutes for a total of ~288 times each day. He has maintained the same measurement pattern to the present day. In his research work, he uses his CGM sensor glucose at a time interval of 15 minutes (96 data per day). Incidentally, the difference in average sensor glucoses between 5-minute intervals and 15-minute intervals is only 0.7% *(average glucose of 112.15 mg/dL for 5-minutes and average glucose of 111.33 mg/dL for 15-minutes with a correlation of 96% between these two sensor glucose curves)* during the period from 2/19/20- to 5/9/212.



Therefore, over the past 12 years, he could study and analyze the collected ~3 million data regarding his health status, medical conditions, and lifestyle details. He applies his knowledge, models, and tools from mathematics, physics, engineering, and computer science to conduct his medical research work. His research is based on the aims of achieving both "high precision" with "quantitative proof" in the medical findings.

The following timetable provides a rough sketch of the emphasis in his medical research during each stage:

· 2000-2013: Self-study diabetes and food nutrition, developing a data collection and analysis software.
· 2014: Develop a mathematical model of metabolism, using engineering modeling and advanced mathematics.
· 2015: Weight & FPG prediction models, using neuroscience.
· 2016: PPG & HbA1C prediction models, using optical physics, artificial intelligence (AI), and neuroscience.
· 2017: Complications due to macro-vascular research, such as Cardiovascular disease (CVD), coronary heart diseases (CHD), and stroke, using pattern analysis and segmentation analysis.
· 2018: Complications due to micro-vascular research such as kidney (CKD), bladder, foot, and eye issues (DR).
· 2019: CGM big data analysis, using wave theory, energy theory, frequency domain analysis, quantum mechanics, and AI.
· 2020: Cancer, dementia, longevity, geriatrics, DR, hypothyroidism, diabetic foot, diabetic fungal infection, and linkage between metabolism and immunity, learning about certain infec-

tious diseases, such as COVID-19.
· 2021: Applications of linear elastic glucose theory (LEGT) and perturbation theory from quantum mechanics on medical research subjects, such as chronic diseases and their complications, cancer, and dementia.
· 2022: Applications of viscoelastic/viscoplastic glucose theory (LEGT) on 73 biomedical research cases.

Again, to date, he has spent around 40,000 hours self-studying and researching medicine. He has collected and calculated more than three million pieces of data regarding his medical conditions and lifestyle details. In addition, he has written 663 medical research notes and published ~600 papers in 100+ various medical and engineering journals. Moreover, he has also given ~120 presentations at ~65 international medical conferences. He has continuously dedicated his time (11-12 hours per day and work each day of a year, without rest) and efforts to his medical research work and shared his findings and learnings with other patients worldwide.

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 to 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 counterpart is "when cause or risk factors are reduced or removed, the symptoms of the 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 material property that exhibits viscous and elastic characteristics when undergoing deformation. Synthetic polymers, wood, and human tissue, as well as metals at high temperatures, display significant viscoelastic effects. In some applications, even a small viscoelastic response can be significant.

Viscoelastic behavior means the material has "time-dependent" characters. Biomedical data, i.e. biomarkers, are time-dependent due to body cells being 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 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 causing force is applied to it.*

The following brief introductions are excerpts from Wikipedia:

"Elasticity (Physics)
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.

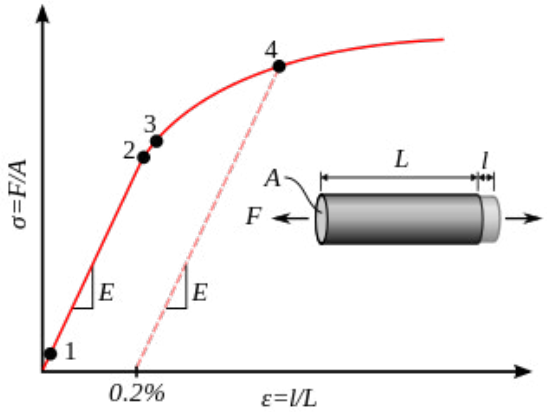
Hooke's law states that the force required to deform elastic objects should be directly proportional to the distance of deformation, regardless of how large that distance becomes. This is known as perfect elasticity, in which a given object will return to its original shape no matter how strongly it 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 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 in its original length, similar to a non-diabetes person or less-severed type 2 diabetes (T2D) patient.*

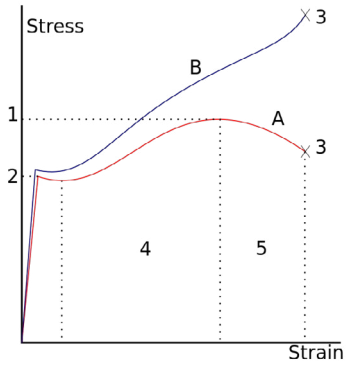
Plasticity (Physics)
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

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 is 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 the 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 the 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 brought down to a healthy level of PPG even with a significant amount of exercise. This means that the PPG level has exceeded its "elastic limit" and entered 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 the 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).**

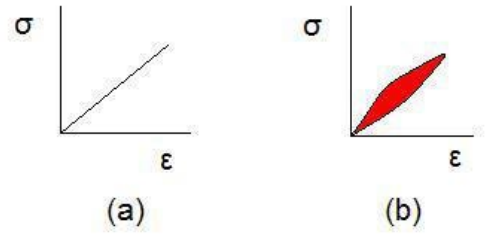
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit 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**
- **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)
= dε/dt * η

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

Results

Figure 1 shows the hysteresis loops with a data table of both 120 mg/dL and 99 mg/dL baselines in the VGT operations.

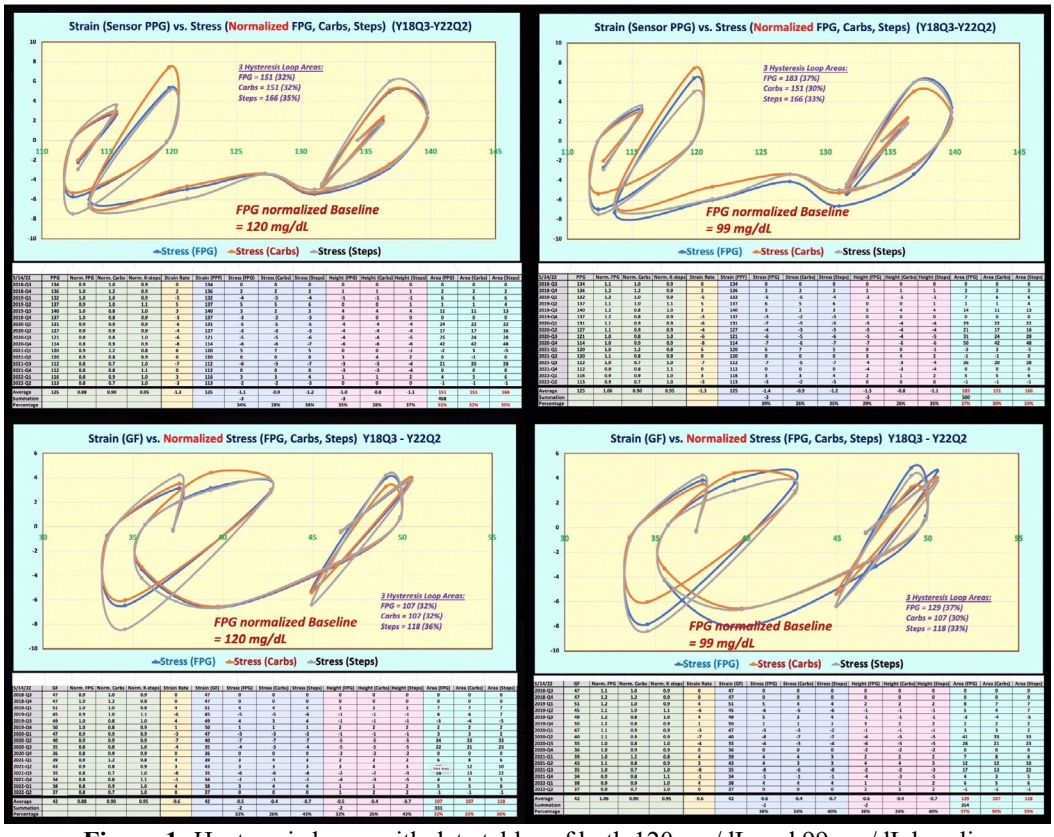
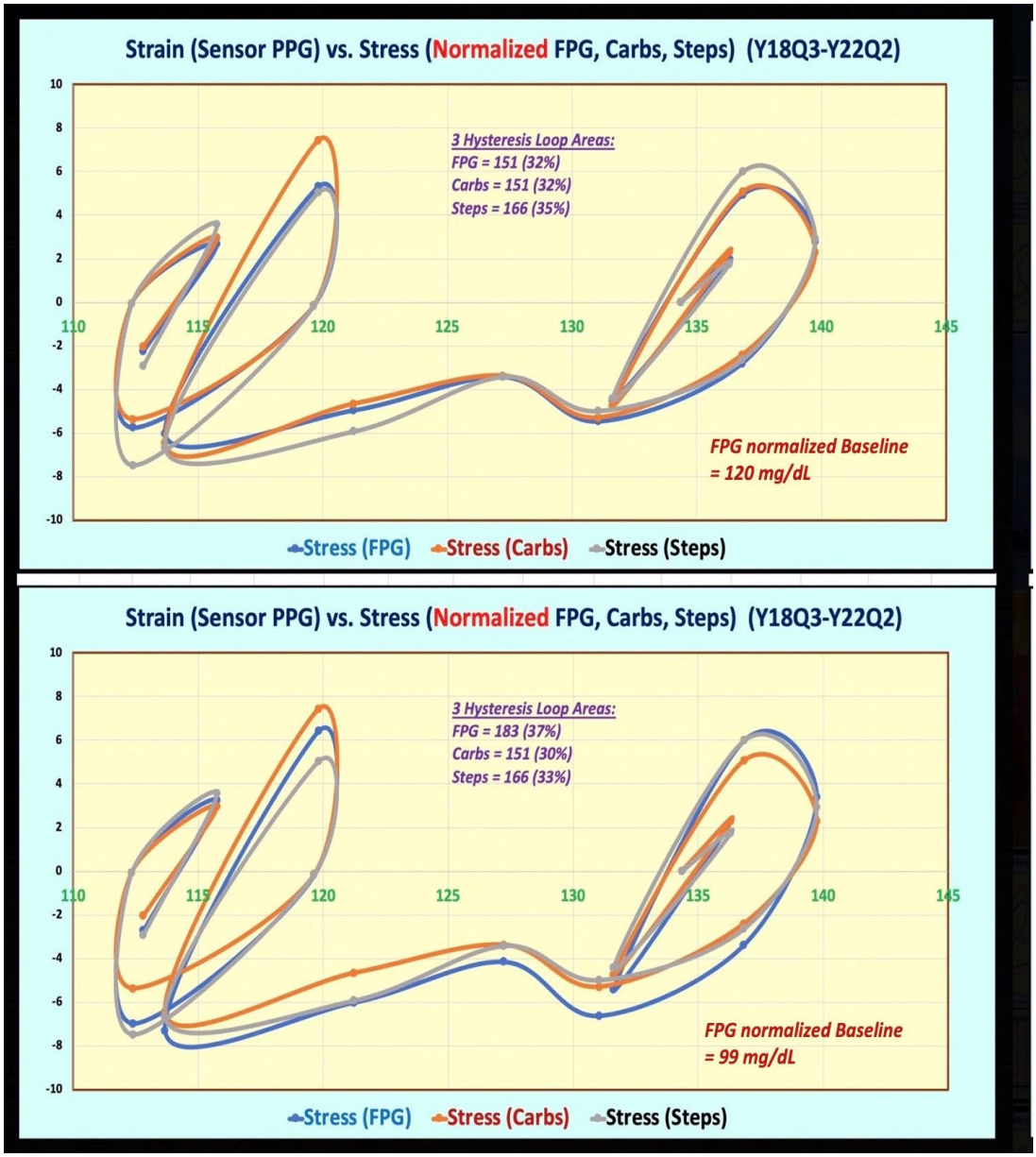


Figure 1: Hysteresis loops with data tables of both 120 mg/dL and 99 mg/dL baselines

Figure 2 depicts 4 VGT stress-strain diagrams & associated hysteresis loop areas with both 120 mg/dL and 99 mg/dL baselines.



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Conclusions

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References

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