Viscoelastic and Viscoplastic Glucose Theory (VGT #32): A Step-By-Step Illustration of how to Apply VGT and Viscoelasticity Perturbation Model with the Average Value of normalized body weight and body temperature in early morning as the viscosity factor to predict average fasting plasma glucose values over 7-hours of sleep time based on GH-Method: math-physical medicine (No. 613)

Gerald C Hsu

EclaireMD Foundation, USA

*Corresponding author
Gerald C Hsu, EclaireMD Foundation, USA

Submitted: 15 Jun 2022; **Accepted:** 20 Jun 2022; **Published:** 02 Jul 2022

Abstract

The author has studied strength of materials and theory of elasticity through his undergraduate courses at the University of Iowa. He also conducted research work and earned a master's degree in Biomechanics under Professor James Andrews. In 1970-1971, he used a combined spring and dashpot model to simulate the behaviors of human joints, bones, muscles, and tendons (which he took some related courses at School of Medicine at UI) in order to investigate the soldier-weapon biophysical interactions during the Vietnam war era. Later, he went to MIT to pursue his PhD study under Professor Norman Jones, who taught him theory of plasticity and dynamic plastic behaviors of various structure elements. To further his education, he took additional graduate courses in various fields of fluid dynamics, thermodynamics, bridge design using energy absorption pad, and soil mechanics under earthquake strike forces which deal with "time-dependency" issues.

Since then, many advancements have been made in the biomechanics branch, especially with human body live tissues that possess certain viscoelastic characteristics, such as bones, muscles, cartilages, tendons (connect bone to muscle), ligaments (connect bone to bone), fascia, and skin. For example, the author suffered plantar fasciitis for many years. He understood that the night splint dorsiflexes forefoot, at the back of the foot, increases plantar fascia tension to offer stress-relief for the pain. This model where muscles and tendons connect the lower leg and foot is a form of viscoelastic study for medical problem solving.

*When dealing with human internal organs, it is not easy to conduct live experiments to obtain accurate measurements for the biomedical material properties. Blood itself is a viscous material (time-dependent) and its viscosity factor may fall between water, honey, syrup, or gel. However, the author's research focus is on "glucose" where the blood sugar amount is produced by the liver and carried by red blood cells, not the blood itself. The postprandial plasma glucose (PPG) is strongly influenced by both energy input via carbs/sugar amount (~60%) and energy output via post-meal exercise level (~40%). Fundamentally, the PPG level is also dependent on the individual's health conditions in regard to liver cells and pancreatic beta cells, which produce glucose and release insulin to control the glucose level in blood. With regard to FPG, there are many influential factors. **In this article, the author selects both body weight and body temperature as the inter-influential factors of FPG.** Therefore, it is nearly impossible to measure the material geometry or material properties to determine the viscosity of "glucose" like in engineering research work. As a result, the best the author could do is **to apply the "concept" of viscoelasticity and/or viscoplasticity" to construct an analogy model of time-dependent glucose behaviors.***

*The author's background includes mathematics, physics, and various engineering disciplines, not including biology and chemistry. He can only investigate the observed biophysical phenomena in the medical field using his ready-learned math-physical tools. For example, he studied both modern physics and quantum mechanics during his school days; therefore, he applied the theory of relativity on interactions among the organs in the human body (an inner space) which is similar to the inter-relationships among the planets in the universe (an outer space). This analogy of using the theory of relativity has been applied in medicine by the author during past few years to identify and prove the inter-connectivity of internal organs. **This article has demonstrated the close inter-relationship among three***

biomarkers, fasting plasma glucose (FPG), body weight, and body temperature along with predicting the FPG level via influential factors such as combined body weight and body temperature.

By utilizing the perturbation theory, he was able to obtain an approximate but accurate predicted glucose level along with the estimation for the associated energy of glucose. In addition, he conducted some investigations on glucose behaviors using elasticity theory and plasticity theory (both static and dynamic), which allowed him to write a few articles on his research findings.

Recently, the author has received an email from Professor Norman Jones, his academic advisor at MIT. Professor Jones wrote that: "I have wondered if the use of viscoelastic/viscoplastic materials might be of some value to your studies. These phenomena embrace time-dependent behaviour and I know that you have emphasized the time-dependence of various behaviours in the body. Just a thought." His suggestion has triggered the author's strong interest and desire to research this subject on glucose behaviors further by using the viscosity theory.

*Nevertheless, the medical field is still quite different from the engineering field, where the engineering materials such as steel, copper, concrete, and aluminum are **inorganic** in most cases. These material properties do not change significantly over their expected lifespans. However, in medicine, the human body with its internal organs and cells are **organic** and go through many distinct stages over their natural lifespans, such as birth, splitting, growth, development, mutation, repair, sickness, and death. Therefore, **the biomedical properties are "moving targets" which vary with the individual person, severity of diseases, and selected different time-windows.** In other words, **they are both time-dependent and specimen-dependent.** Furthermore, some basic engineering material characteristics, such as calculations for the cross-section of a subject, bending moment of resistance, or the shape factors in solid mechanics, are not applicable in this biomedical glucose analogy study of elasticity/plasticity or viscoelasticity/viscoplasticity. In the author's opinion, the most important part is that by **applying the concept** of elasticity/plasticity theory or viscoelasticity/viscoplaciticity theory on understanding or illustrating the observed biomedical phenomena is extremely useful to explore deep insights or enable the prediction of important biomarkers, such as glucoses, particularly for **both hyperglycemic conditions (leading into various internal organ complications) and hypoglycemic conditions (insulin shock leading to possible sudden death).***

*In this particular viscoelasticity study, he utilized a continuous glucose monitoring (CGM) device to collect his FPG values at each 15-minute time intervals **during the 7 hours of sleep timespan.***

In this article, the author decides to omit a detailed explanation of the basic concepts for elasticity, plasticity, viscoelasticity, viscoplasticity, and perturbation theories from the disciplines of engineering and physics in the Method section. Instead, he describes the step-by-step procedures on how to calculate his predicted sensor FPG.

In conclusion, the author has defined his stress-strain equations as follows:

strain
= ε
= Sensor FPG value of each day

Viscosity Factor
= η
= ((body weight / average body weight) + (body temperature / average body temperature)) / 2 of each day

However, he has utilized the FPG change rate multiplied by the above described viscosity factor to obtain the stress:

Stress
= η * (dε/dt)
= η * (d-strain/d-time)
= ((viscosity factor of present month) * (FPG of present month - FPG of previous month) / 7))

Where 7 indicates the 7-hour time span of his average sleep hours.
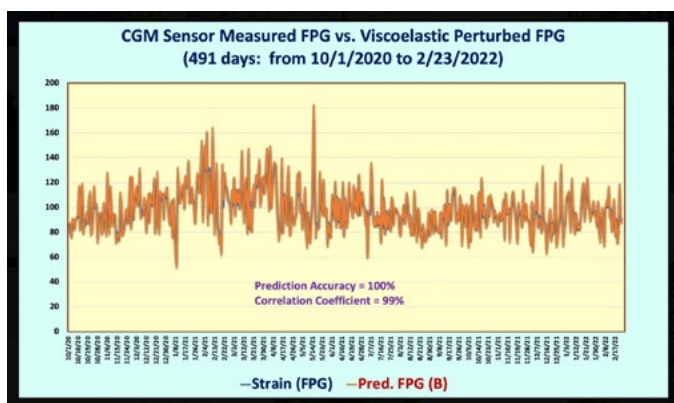
Based on the stress-strain analysis in a spatial-domain (SD) and the application of the theories of viscoelasticity, viscoplasticity, and perturbation model, the following four observations are evident:

(1) From a time-domain analysis (TD) among 3 moving-averaged values of FPG, body weight, and body temperature, there are high correlation coefficients (52%, 71%, 84%) existing between 3 subsets of these 3 biomarkers.
(2) Observing from the stress-strain diagram in SD, the measured FPG using the combined weight and temperature as the viscosity factor has shown a "pseudo-viscoelastic" behavior (starting FPG of 88 mg/dL and ending FPG of 91 mg/dL are extremely close to each other).
(3) The stress-strain curve appears to be complicated due to its 491 datasets. However, two extreme biomedical situations of both hypoglycemia (around 50 mg/dL on left side) and hyperglycemia (above 150 mg/dL on right side) are

clearly observed. The majority of FPG are centered around 90 mg/dL to 100 mg/dL.
(4) The predicted FPG values using viscoelastic perturbation method have achieved extremely high prediction accuracy of 100% and correlation coefficient of 99% in comparison with the measured FPG data and waveform. ***The most important detail is that this prediction model only utilizes one set of measured FPG data and pattern and his ready-calculated FPG prediction values from previous days.*** *Furthermore, this highly accurate FPG prediction model includes the combined effect from the average of the normalized body weight and normalized body temperature.*

*In summary, from a daily practice viewpoint, using **an average normalized body weight and normalized body temperature as the viscosity factor and applying the viscoelastic perturbation model** can produce a satisfactory prediction of FPG in the early morning without the effort of measuring glucose. But, from time to time, a calibration effort is still recommended since the "FPG change rates" are still based on the measured FPG data.*

CGM Sensor Measured FPG vs. Viscoelastic Perturbed FPG
(491 days: from 10/1/2020 to 2/23/2022)

Prediction Accuracy = 100%
Correlation Coefficient = 99%

—Strain (FPG) —Pred. FPG (B)

Introduction

The author has studied strength of materials and theory of elasticity through his undergraduate courses at the University of Iowa. He also conducted research work and earned a master's degree in Biomechanics under Professor James Andrews. In 1970-1971, he used a combined spring and dashpot model to simulate the behaviors of human joints, bones, muscles, and tendons (which he took some related courses at School of Medicine at UI) in order to investigate the soldier-weapon biophysical interactions during the Vietnam war era. Later, he went to MIT to pursue his PhD study under Professor Norman Jones, who taught him theory of plasticity and dynamic plastic behaviors of various structure elements. To further his education, he took additional graduate courses in various fields of fluid dynamics, thermodynamics, bridge design using energy absorption pad, and soil mechanics under earthquake strike forces which deal with "time-dependency" issues.

Since then, many advancements have been made in the biomechanics branch, especially with human body live tissues that possess certain viscoelastic characteristics, such as bones, muscles, cartilages, tendons (connect bone to muscle), ligaments (connect bone to bone), fascia, and skin. For example, the author suffered plantar fasciitis for many years. He understood that the night splint dorsiflexes forefoot, at the back of the foot, increases plantar fascia tension to offer stress-relief for the pain. This model where muscles and tendons connect the lower leg and foot is a form of viscoelastic study for medical problem solving.

When dealing with human internal organs, it is not easy to conduct live experiments to obtain accurate measurements for the biomedical material properties. Blood itself is a viscous material (time-dependent) and its viscosity factor may fall between water, honey, syrup, or gel. However, t*he author's research focus is on "glucose" where the blood sugar amount is produced by*

the liver and carried by red blood cells, not the blood itself. The *postprandial plasma glucose (PPG) is strongly influenced by both energy input via carbs/sugar amount (~60%) and energy output via post-meal exercise level (~40%). Fundamentally, the PPG level is also dependent on the individual's health conditions in regard to liver cells and pancreatic beta cells, which produce glucose and release insulin to control the glucose level in blood. With regard to FPG, there are many influential factors.* ***In this article, the author selects both body weight and body temperature as the inter-influential factors of FPG.*** Therefore, it is nearly impossible to measure the material geometry or material properties to determine the viscosity of "glucose" like in engineering research work. As a result, the best the author could do is ***to apply the "concept" of viscoelasticity and/or viscoplasticity" to construct an analogy model of time-dependent glucose behaviors.***

The author's background includes mathematics, physics, and various engineering disciplines, not including biology and chemistry. He can only investigate the observed biophysical phenomena in the medical field using his ready-learned math-physical tools. For example, he studied both modern physics and quantum mechanics during his school days; therefore, he applied the theory of relativity on interactions among the organs in the human body (an inner space) which is similar to the inter-relationships among the planets in the universe (an outer space). This analogy of using the theory of relativity has been applied in medicine by the author during past few years to identify and prove the inter-connectivity of internal organs. ***This article has demonstrated the close inter-relationship among three biomarkers, fasting plasma glucose (FPG), body weight, and body temperature along with predicting the FPG level via influential factors such as combined body weight and body temperature***.

By utilizing the perturbation theory, he was able to obtain an approximate but accurate predicted glucose level along with the estimation for the associated energy of glucose. In addition, he conducted some investigations on glucose behaviors using elasticity theory and plasticity theory (both static and dynamic), which allowed him to write a few articles on his research findings.

Recently, the author has received an email from Professor Norman Jones, his academic advisor at MIT. Professor Jones wrote that: *"I have wondered if the use of viscoelastic/viscoplastic materials might be of some value to your studies. These phenomena embrace time-dependent behaviour and I know that you have emphasized the time-dependence of various behaviours in the*

body. Just a thought." His suggestion has triggered the author's strong interest and desire to research this subject on glucose behaviors further by using the viscosity theory.

Nevertheless, the medical field is still quite different from the engineering field, where the engineering materials such as steel, copper, concrete, and aluminum are inorganic in most cases. These material properties do not change significantly over their expected lifespans. However, in medicine, the human body with its internal organs and cells are organic and go through many distinct stages over their natural lifespans, such as birth, splitting, growth, development, mutation, repair, sickness, and death. Therefore, the biomedical properties are "moving targets" which vary with the individual person, severity of diseases, and selected different time-windows. In other words, they are both time-dependent and specimen-dependent. Furthermore, some basic engineering material characteristics, such as calculations for the cross-section of a subject, bending moment of resistance, or the shape factors in solid mechanics, are not applicable in this biomedical glucose analogy study of elasticity/plasticity or viscoelasticity/viscoplasticity. In the author's opinion, the most important part is that by applying the concept of elasticity/plasticity theory or viscoelasticity/viscoplaciticity theory on understanding or illustrating the observed biomedical phenomena is extremely useful to explore deep insights or enable the prediction of important biomarkers, such as glucoses, particularly for both hyperglycemic conditions (leading into various internal organ complications) and hypoglycemic conditions (insulin shock leading to possible sudden death).

In this particular viscoelasticity study, he utilized a continuous glucose monitoring (CGM) device to collect his FPG values at each 15-minute time intervals during the 7 hours of sleep timespan.

In this article, the author decides to omit a detailed explanation of the basic concepts for elasticity, plasticity, viscoelasticity, viscoplasticity, and perturbation theories from the disciplines of engineering and physics in the Method section. Instead, he describes the step-by-step procedures on how to calculate his predicted sensor FPG.

Methods
Step-by-step procedures of Predicted FPG using weight and temperature:
In this particular paper, the author displays his step-by-step procedures regarding the predicted FPG using a visco-perturbation model:

(1) Collect daily average FPG data as the "strain" values.
(2) Collect corresponding daily body weights and body temperatures in the early morning as FPG's influential factors.
(3) Calculate the "normalized weight or temperature" as follows: *Normalized weight = (weight at present day) / (average weight from first day to present day); Normalized temp = (temp at present day) / (average temp from first day to present day).*
(4) Calculate the viscosity factor (η) as the average value of both normalized body weight and normalized body temperature; i.e.

η = *(normalized weight + normalized temperature) / 2*
(5) Calculate the "stress" as "strain (FPG) change rate multiplied by the viscosity factor (η)"; or the *stress = ((FPG of previous day - FPG of two-days before) / 7) * ((η = (normalized weight + normalized temperature) / 2)*
(6) Calculate the predicted FPG using the following formula: *Predicted FPG = (predicted FPG value of previous day) + (stress value of present day).* For the first day of this stress dataset, we should preset its stress value at zero.

Here, he uses FPG as the strain and the average amount of both normalized weight and normalized temperature as the viscosity factor. In order to include time-dependent characteristics, he uses the FPG change rate multiplied by this calculated viscosity factor in his stress-strain analysis and viscoelastic perturbation analysis.

Results
Figure 1 shows 3 correlations among FPG, weight, temperature within different timespans.
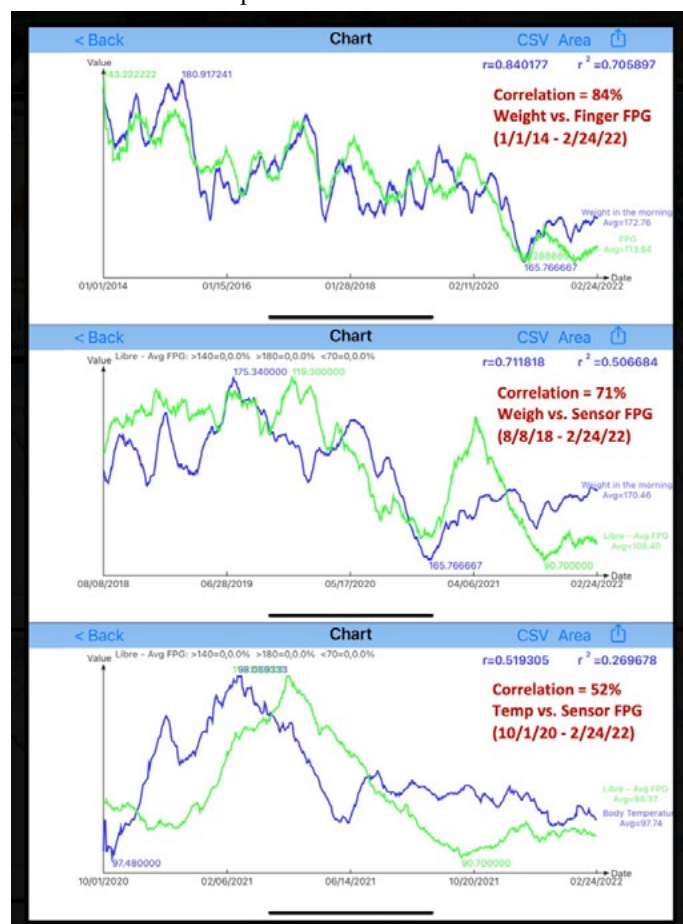

Figure 1: Correlations among FPG, weight, temperature within different timespans

Figure 2 depicts the results from the FPG viscoelastic study. This is the stress-strain diagram which demonstrates the viscoelastic characteristics of measured FPG with a selected viscosity factor of the average value of normalized body weight and normalized body temperature.
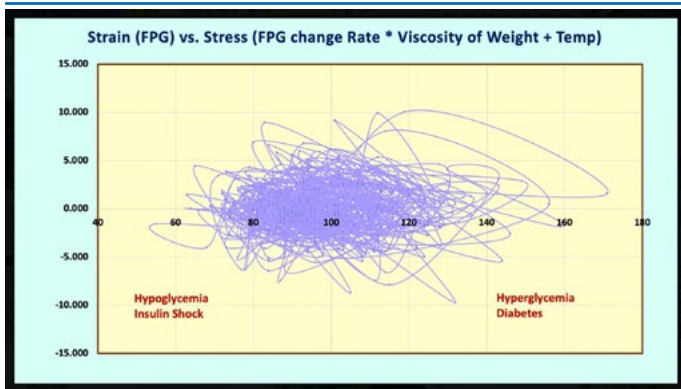
Figure 2: Viscoelastic stress-strain diagram of measured FPG with viscosity factor of averaged value of normalized body weight and normalized body temperature

Figure 3 reveals the comparison of measured FPG versus predicted FPG using an average value of normalized body weight and normalized body temperature, via the viscoelastic perturbation model. The prediction accuracy is 100% and the correlation coefficient between this predicted FPG and the measured FPG is 99%.
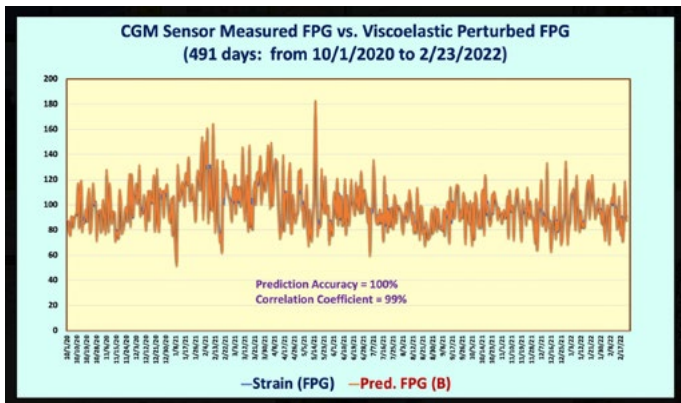

Figure 3: Time-domain comparison between measured FPG and predicted FPG using viscoelastic perturbation model

Conclusion

In conclusion, the author has defined his stress-strain equations as follows:

strain
= ε
= Sensor FPG value of each day

Viscosity Factor
= η
= ((body weight / average body weight) + (body temperature / average body temperature)) / 2 of each day

However, he has utilized the FPG change rate multiplied by the above described viscosity factor to obtain the stress:

Stress
= η * (dε/dt)

= η * (d-strain/d-time)
= ((viscosity factor of present month) * (FPG of present month - FPG of previous month) / 7))

Where 7 indicates the 7-hour time span of his average sleep hours.

Based on the stress-strain analysis in a spatial-domain (SD) and the application of the theories of viscoelasticity, viscoplasticity, and perturbation model, the following four observations are evident:

(1) From a time-domain analysis (TD) among 3 moving-averaged values of FPG, body weight, and body temperature, there are high correlation coefficients (52%, 71%, 84%) existing between 3 subsets of these 3 biomarkers.
(2) Observing from the stress-strain diagram in SD, the measured FPG using the combined weight and temperature as the viscosity factor has shown a "pseudo-viscoelastic" behavior (starting FPG of 88 mg/dL and ending FPG of 91 mg/dL are extremely close to each other).
(3) The stress-strain curve appears to be complicated due to its 491 datasets. However, two extreme biomedical situations of both hypoglycemia (around 50 mg/dL on left side) and hyperglycemia (above 150 mg/dL on right side) are clearly observed. The majority of FPG are centered around 90 mg/dL to 100 mg/dL.
(4) The predicted FPG values using viscoelastic perturbation method have achieved extremely high prediction accuracy of 100% and correlation coefficient of 99% in comparison with the measured FPG data and waveform. **The most important detail is that this prediction model only utilizes one set of measured FPG data and pattern and his ready-calculated FPG prediction values from previous days**. *Furthermore, this highly accurate FPG prediction model includes the combined effect from the average of the normalized body weight and normalized body temperature.*

In summary, from a daily practice viewpoint, using **an average normalized body weight and normalized body temperature as the viscosity factor** and **applying the viscoelastic perturbation model** can produce a satisfactory prediction of FPG in the early morning without the effort of measuring glucose. But, from time to time, a calibration effort is still recommended since the "FPG change rates" are still based on the measured FPG data.

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.

Readers may use this article as long as the work is properly cited, and their use is educational and not for profit, and the author's original work is not altered.