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Viscoelastic or Viscoplastic Glucose Theory (VGT #93): Using a Hybrid Model of Space Domain VGT Energy Method and Frequency Domain Fast Fourier Transform Energy Method from Three VGT Biomedical Research Cases to Identify a More Suitable Selection of Variables Based on GH-Method: Math-Physical Medicine (No. 683)

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Abstract

The author is an engineer who has conducted medical research work over the past 13 years in the fields of endocrinology, metabolic disorder-induced chronic diseases (especially diabetes), and their resulting various medical complications. Thus far, he has written and published nearly 700 research papers in various medical journals using math-physical medicine methodology (MPM). In December 2021, Professor Norman Jones, the author's adviser at MIT, suggested the utilization of the viscoelastic/plastic method from physics and engineering to conduct his medical research work. Since then, beginning with Paper No. 578 dated 1/8/2022, he has written 90+ medical papers, including 4 economic papers, using the VGT research tools. These papers aim to explore some hidden physical behaviors and provide a deeper understanding and a better quantitative description of the inter-relationships of a selected output (symptom) versus singular input or multiple inputs (root causes, risk factors, or influential factors). In the field of medical research, the hidden biophysical behaviors and possible inter-relationships exist among lifestyle details, medical conditions, chronic diseases including obesity, diabetes, hypertension, hyperlipidemia, and induced medical complications, such as heart attacks, stroke, kidney failure, cancers, dementia, and even longevity concerns. In the past 13 years of his medical research work, he has noticed that most medical subjects with their associated data, symptoms, and causes are highly "time-dependent" which means that all biomedical variables change from time to time because body living cells are dynamically changing. Recently, he realized that the VGT theory should not be limited to engineering applications only. Its ability to link certain time-dependent variables and their physical characteristics and associated energy estimation via the hysteresis loop area are equally powerful for applications in medicine as well as many other fields of knowledge, e.g. economics, psychology, and social science. Of course, one of the major challenges of VGT analysis is related to data mining and selection. The author would like to describe the essence of a "hybrid model" that combines the space-domain (SD) viscoelastic /plastic VGT analysis method and the frequency-domain (FD) fast Fourier transform (FFT) analysis method described in 9 steps instead of mathematical equations. This is for readers who do not have an extensive academic background in those subjects of engineering, physics & mathematics - several excerpts from Wikipedia are included in the Method section of this full-text article. The first step is to collect the output data or symptom (strain or ε) on a time scale. The second step is to calculate the output change rate with time (dε/dt), i.e. the change rate of strain or symptom over each period. The third step is to gather the input data or cause (viscosity or η) on a time scale. The fourth step is to calculate the time-dependent input or cause (time-dependent stress or σ) by multiplying dε/dt and η together. The "time-dependent input or cause equation" of "stress σ = strain change rate of dε/dt * viscosity η" is the essential part of "time-dependency". The fifth step is to plot the input-output (i.e. stress-strain or cause-symptom) curve in a 2-dimensional space domain or SD (x-axis versus y-axis) with strain (output or symptom) on the x-axis and stresses (time-dependent inputs, causes, or stresses) on the y-axis. The sixth step is to calculate the total enclosed area within these stress-strain curves or input-output curves (i.e. the hysteresis loops), which is also an indicator of associated energies (either created energy or dissipated energy) of this input and output dataset. These energy values can also be

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*Corresponding author: Gerald C. Hsu, eclaireMD Foundation, USA considered as the degrees of influence on output by inputs. The seventh step is to define a "hybrid input variable" by either using "strain*stress" which yields a more accurate estimation of energy similar to the SD-VGT energy associated with the hysteresis loop or using "strain*viscosity." which yields a less accurate estimation of energy. The eighth step is to present these hybrid models' results of both "strain*stress" and "strain*viscosity" in TD and then perform the FFT operation to convert them into FD. The enclosed area of the FD curve (where the x-axis is the frequency and the y-axis is the amplitude of energy) can be used to estimate the total FD-FFT energy. The ninth step is to compare these two hybrid model results by using both "strain*stress" and "strain*viscosity" in FD against the VGT results in SD. After providing the above 9-step description, the author would like to use the following set of VGT stress-strain equations in a 2-dimensional SD to address the unique "time-dependency characteristics" of selected medical variables: Strain = ε = individual strain value at the present time duration. Stress = σ (based on the change rate of strain multiplying with a chosen viscosity factor η) = η * (dε/dt) = η * (d-strain/d-time) = (viscosity factor η using individual viscosity factor at present time duration) * (strain at present quarter - strain at previous time duration). Some of these inputs (causes or viscosity factors) are further normalized by dividing them by the average number of viscosity or a certain established health standard, such as 120 mg/dL for glucose, 25 for body mass index (BMI), 4,000 steps after each meal, 15 grams of carbs/sugar intake amount per meal, 50% as a "break-even" risk level of medical complications, etc. Using the originally collected data, i.e. the non-normalized data, it would distort the numerical comparison of the hysteresis loop areas. This normalization process can remove the dependency of the individual unit or certain unique characteristics associated with each viscosity factor. This process allows him to convert the originally collected variables into a set of "dimensionless variables" for easier numerical comparison and result interpretation. In this particular report, he has chosen the following two different FD-FFT cases for FD-FFT energy results comparison against the SD-VGT energy results: The first FD case uses the variables of (strain*viscosity), e.g. CVD*eAG, CVD*BW, and CVD*Food. The second FD case uses the variables of (strain*stress), e.g. CVD*(CVD rate*eAG), CVD*(CVD rate*BW), and CVD*(CVD rate*Food). The second FD case utilized the "strain rate" component in the defined FD-FFT variable of the first FD case which then changed the variable of (strain*viscosity) into a new variable of (strain*stress). Please note that the defined equation of "stress = strain rate * viscosity". Therefore, the second FD case would capture additional influences resulting from the fluctuation of strain (e.g. CVD change rate) over time, which is the strain change rate, or dε/dt. Based on his learned characteristics of the behaviors of VGT results, he has predicted that the second case of using the (strain*stress) variable would yield a more appropriate result than using the (strain*viscosity) variable. In summary, there are 4 observations from applying his newly-defined "hybrid model" that combined the SD-VGT and FD-FFT methods along with data from three medical papers, PPG vs. FPG, carbs/sugar amount, walking k-steps (No. 676); CVD/Stroke risk % vs. estimated daily average glucose, body weight, food portion % (No.677); and Longevity vs. CVD risk % from arteries damage of heart/brain, CKD risk from kidney failure, T2D diabetes, and its various induced medical complications (No. 680): (1) From a biomedical perspective, the author's reasons for choosing these 3 SD-VGT analysis cases and their data are summarized as follows: In the first case study in Paper No. 676, fasting plasma glucose (FPG) serves as the baseline of postprandial plasma glucose (PPG) which are resulted from a type 2 diabetes (T2D) patient's pancreatic beta cells damage and their health consequences. Pancreatic beta cells' insulin secretion and quality have contributed about 70% to 90% to the patient's PPG level. The remaining 10% to 30% of PPG wave fluctuation after each meal is mainly dependent on the patient's carbohydrates and sugar intake amount (carbs) and post-meal walking exercise steps (k-steps). In the second case study in Paper No. 677, a patient who suffers heart attacks from cardiovascular disease and/or stroke (CVD risk) has three known major influential factors. Estimated daily average glucose (eAG) which has PPG as its major contributor; body weight (BW) is a strong influential factor of both T2D and CVD, and food that contains both food quality (influences on weight, diabetes, hyperlipidemia, and hypertension) and food quantity (directly contributes to obesity and T2D). In the third case study in Paper No. 680, a patient's longevity concerns or perspectives are strongly dependent upon CVD risk of having heart attacks or stroke, CKD risk of developing kidney failures, and diabetes condition-induced complications such as CVD, CKD, and cancers. Although patients can die from many other diseases, heart failure and stroke have been the number one causes of death in the USA, followed by cancer at number two, while diabetes is ranked number eight. (2) From Figure 1 in the first case of Paper No. 676, PPG vs. FPG, carbs, k-steps, its SD-VGT results are: FPG=38%, Carbs=31%, K-steps=31%; its FD-FFT results using strain*stress are: FPG=44%, Carbs=30%, K-steps=26% and a correlation of 98% with SD (very good fit with SD); but its FD-FFT results using strain*viscosity are: FPG=35%, Carbs=54%, K-steps=11% and a correlation of 7% with SD which does not fit with SD at all. (3) From Figure 2 in the second case of Paper No. 677, CVD risk vs. eAG, BW, Food, its SD-VGT results are: eAG=36%, BW=34%, Food=30%; its FD-FFT results using

strain*stress are: eAG=38%, BW=34%, Food=28% and a correlation of 100% with SD, almost a perfect fit with SD; but its FD-FFT results using strain*viscosity are: eAG=31%, BW=23%, Food=46% and a correlation of -78% with SD which does not fit with SD at all. (4) From Figure 3 in the third case of Paper No. 680, Longevity vs. CVD, CKD, T2D, its SD-VGT results are CVD=32%, CKD=38%, T2D=30%; its FD-FFT results using strain*stress are: CVD=29%, CKD=44%, T2D=27% and a correlation of 99% with SD which fits with SD very well but its FD-FFT results using strain*viscosity are: CVD=31%, CKD=46%, T2D=23% and a correlation of 99% with SD which also fits with SD very well. Please note that the longevity case has an equal level of results fit. The reason for these two equal values of highly correlated FD-FFT energies with SD-VGT is that these 3 variables of longevity (1 output), CVD risk, and CKD risk (2 inputs) are developed using the same metabolism index (MI) model with highly similar inputs and equations. This particular paper has utilized three papers, No. 680, No. 677, and No.676, as the data source and SD energy results for the hybrid model result comparison. In conclusion, the author has identified that the hybrid model of SD-VGT and FD-FFT using the “strain*stress” variable has offered better-fit results in comparison with the counterpart SD-VGT results than using the “strain*viscosity” variable. With this expectation developed from his past observations from 90+ medical research exercises, he can make a solid prediction before performing the analysis that the (strain*stress) variable would offer a better-fit FD-FFT energy result than the (strain*viscosity) variable in comparison to the SD-VGT energy result. However, the FD-FFT of (strain*viscosity) variable lacks the necessary component of strain change rate, i.e. dε/dt; therefore, it does not include sufficient influences from the “time-dependent” strain characteristics, i.e. medical symptoms fluctuation.

Keywords: Viscoelastic; Viscoplastic; Cardiovascular disease; Body weight; Postprandial plasma glucose; Fasting plasma glucose; Type 2 diabetes; Fast Fourier transform

Abbreviations: BW: body weight; CVD: cardiovascular disease; FFT: fast Fourier transform; T2D: type 2 diabetes; PPG: postprandial plasma glucose; FPG: fasting plasma glucose; FD: frequency domain; SD: space domain; TD: time domain; MPM: math-physical medicine

1. INTRODUCTION

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Strain
= ε
= individual strain value at the present time duration

Stress
= σ (based on the change rate of strain multiplying with a chosen viscosity factor η)
= η * (dε/dt)
= η * (d-strain/d-time)
= (viscosity factor η using individual viscosity factor at present time duration) * (strain at present quarter - strain at previous time duration)

Some of these inputs (causes or viscosity factors) are further normalized by dividing them by the average number of viscosity or a certain established health standard, such as 120 mg/dL for glucose, 25 for body mass index (BMI), 4,000 steps after each meal, 15 grams of carbs/sugar intake amount per meal, 50% as a "break-even" risk level of medical complications, etc. Using the originally collected data, i.e. the non-normalized data, it would distort the numerical comparison of the hysteresis loop areas. This normalization process can remove the dependency of the individual unit or certain unique characteristics associated with each viscosity factor. This process allows him to convert the originally collected variables into a set of "dimensionless variables" for easier numerical comparison and result interpretation.

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2. METHODS

2.1 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 regarding his need for kidney dialysis treatment and his future high risk of dying from his severe diabetic complications. Other than the cerebrovascular disease (stroke), he has suffered most of the known diabetic complications, including both macro-vascular and micro-vascular 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 5/9/22.

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 infectious 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 81 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 676 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.

2.2 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 the history of his personalized diabetes research, 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.

2.3 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.

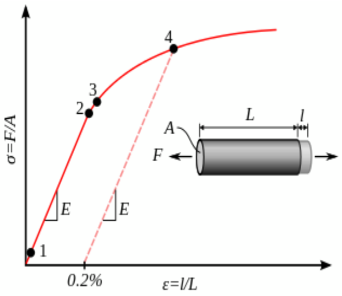
In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic 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):

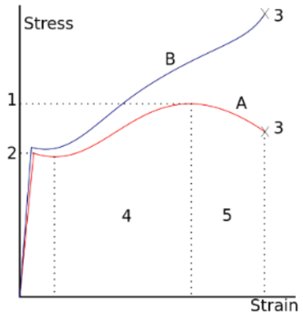
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

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 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 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).

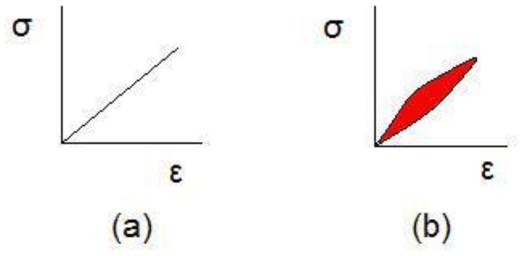
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit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

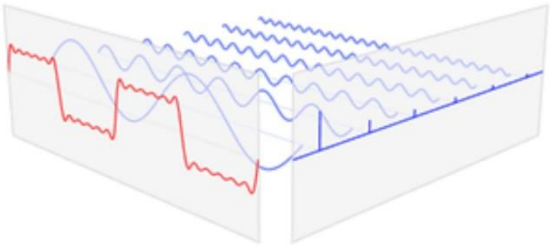
Medical analogy: In viscoelastic or viscoplastic analysis, the stress component equals the strain change rate of time multiplying with the viscosity factor, or

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
= $\oint \sigma d\varepsilon$

2.4 From time-domain to frequency domain via Fourier transform

In physics, electronics, control systems engineering, and statistics, the frequency domain refers to the analysis of mathematical functions or signals concerning frequency, rather than time.[1] Put simply, a time-domain graph shows how a signal changes over time, whereas a frequency-domain graph shows how much of the signal lies within each given frequency band over a range of frequencies. A frequency-domain representation can also include information on the phase shift that must be applied to each sinusoid to be able to recombine the frequency components to recover the original time signal.



The Fourier transform converts the function's time-domain representation, shown in red, to the function's frequency-domain representation, shown in blue. The component frequencies, spread across the frequency spectrum, are represented as peaks in the frequency domain.

A given function or signal can be converted between the time and frequency domains with a pair of mathematical operators called transforms. An example is the Fourier transform, which converts a time function into a complex-valued sum or integral of sine waves of different frequencies, with amplitudes and phases, each of which represents a frequency component. The "spectrum" of frequency components is the frequency-domain representation of the signal. The inverse Fourier transform converts the frequency-domain function back to the time-domain function. A spectrum analyzer is a tool commonly used to visualize electronic signals in the frequency domain.

Advantages

One of the main reasons for using a frequency-domain representation of a problem is to simplify the mathematical analysis. For mathematical systems governed by linear differential equations, a very important class of systems with many real-world applications, converting the description of the system from the time domain to a frequency domain converts the differential equations to algebraic equations, which are much easier to solve.

In addition, looking at a system from the point of view of frequency can often give an intuitive understanding of the qualitative behavior of the system, and a revealing scientific nomenclature has grown up to describe it, characterizing the behavior of physical systems to time-varying inputs using terms such as bandwidth, frequency response, gain, phase shift, resonant frequencies, time constant, resonance width, damping factor, Q factor, harmonics, spectrum, power spectral density, eigenvalues, poles, and zeros.

An example of a field in which frequency-domain analysis gives a better understanding than the time domain is music; the theory of operation of musical instruments and the musical notation used to record and discuss pieces of music is implicitly based on the breaking down of complex sounds into their separate component frequencies (musical notes).

Magnitude and phase

In using the Laplace, Z-, or Fourier transforms, a signal is described by a complex function of frequency: the component of the signal at any given frequency is given by a complex number. The modulus of the number is the amplitude of that component, and the argument is the relative phase of the wave. For example, using the Fourier transform, a sound wave, such as human speech, can be broken down into its component tones of different frequencies, each represented by a sine wave of different amplitude and phase. The response of a system, as a function of frequency, can also be described by a complex function. In many applications, phase information is not important. By discarding the phase information, it is possible to simplify the information in a frequency-domain representation to generate a frequency spectrum or spectral density. A spectrum analyzer is a device that displays the spectrum, while the time-domain signal can be seen on an oscilloscope.

Types

Although "the" frequency domain is spoken of in the singular, there are several different mathematical transforms that are used to analyze time-domain functions and are referred to as "frequency domain" methods. These are the most common transforms and the fields in which they are used:

- Fourier series – periodic signals, oscillating systems.
- Fourier transform – aperiodic signals, transients.
- Laplace transform – electronic circuits and control systems.
- Z transform – discrete-time signals, digital signal processing.
- Wavelet transform — image analysis, data compression.

More generally, one can speak of the transform domain concerning any transform. The above transforms can be interpreted as capturing some form of frequency, and hence the transform domain is referred to as a frequency domain.

Discrete frequency domain

The Fourier transform of a periodic signal has energy only at a base frequency and its harmonics. Another way of saying this is that a periodic signal can be analyzed using a discrete frequency domain. Dually, a discrete-time signal gives rise to a periodic frequency spectrum. Combining these two, if we start with a time signal which is both discrete and periodic, we get a frequency spectrum that is also both discrete and periodic. This is the usual context for a discrete Fourier transform.

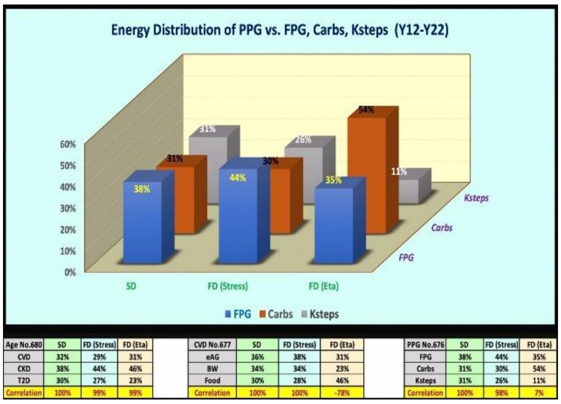
History of term

The use of the terms "frequency domain" and "time domain" arose in communication engineering in the 1950s and early 1960s, with "frequency domain" appearing in 1953. See time domain: the origin of the term for details.

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 energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 676.



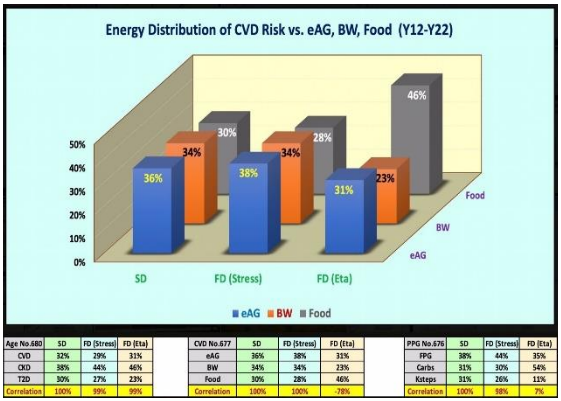
Age No.680	SD	FD (Stress)	FD (Eta)
CVD	32%	29%	31%
CKD	38%	44%	46%
T2D	30%	27%	23%
Correlation	100%	99%	99%

CVD No.677	SD	FD (Stress)	FD (Eta)
eAG	36%	38%	31%
BW	34%	34%	23%
Food	30%	28%	46%
Correlation	100%	100%	-78%

PPG No.676	SD	FD (Stress)	FD (Eta)
FPG	38%	44%	35%
Carbs	31%	30%	54%
Ksteps	31%	26%	11%
Correlation	100%	98%	7%

Figure 1: Energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 676.

Figure 2 displays energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 677.



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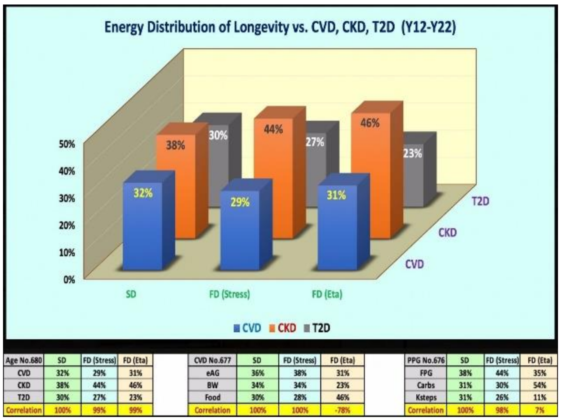
Ksteps	31%	26%	11%
Correlation	100%	98%	7%

Figure 2: Energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 677.

Figure 3 illustrates energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 680.



Age No.680	SD	FD (Stress)	FD (Eta)
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FPG	38%	44%	35%
Carbs	31%	30%	54%
Ksteps	31%	26%	11%
Correlation	100%	98%	7%

Figure 3: Energy results from the hybrid model of combining both SD and FD and using data and energy results from paper No. 680.

4. CONCLUSION

In summary, there are 4 observations from applying his newly-defined "hybrid model" that combined the SD-VGT and FD-FFT methods along with data from three medical papers, PPG vs. FPG, carbs/sugar amount, walking k-steps (No. 676); CVD/Stroke risk % vs. estimated daily average glucose, body weight, food portion % (No.677); and Longevity vs. CVD risk % from arteries damage of heart/brain, CKD risk from kidney failure, T2D diabetes, and its various induced medical complications (No. 680):

(1) From a biomedical perspective, the author's reasons for choosing these 3 SD-VGT analysis cases and their data are summarized as follows: In the first case study in Paper No. 676, fasting plasma glucose (FPG) serves as the baseline of postprandial plasma glucose (PPG) which are resulted from a type 2 diabetes (T2D) patient's pancreatic beta cells damage and their health consequences. Pancreatic beta cells' insulin secretion and quality have contributed about 70% to 90% to the patient's PPG level. The remaining 10% to 30% of PPG wave fluctuation after each meal is mainly dependent on the patient's carbohydrates and sugar intake amount (carbs) and post-meal walking exercise steps (k-steps). In the second case study in Paper No. 677, a patient who suffers heart attacks from cardiovascular disease and/or stroke (CVD risk) has three known major influential factors. Estimated daily average glucose (eAG) which has PPG as its major contributor; body weight (BW) is a strong influential factor of both T2D and CVD, and food that contains both food quality (influences on weight, diabetes, hyperlipidemia, and hypertension) and food quantity (directly contributes to obesity and T2D). In the third case study in Paper No. 680, a patient's longevity concerns or perspectives are strongly dependent upon CVD risk of having heart attacks or stroke, CKD risk of developing kidney failures, and diabetes condition-induced complications such as CVD, CKD, and cancers. Although patients can die from many other diseases, heart failure and stroke have been the number one causes of death in the USA, followed by cancer at number two, while diabetes is ranked number eight.

(2) From Figure 1 in the first case of Paper No. 676, PPG vs. FPG, carbs, k-steps, its SD-VGT results are: FPG=38%, Carbs=31%, K-steps=31%; its FD-FFT results using strain*stress are: FPG=44%, Carbs=30%, K-steps=26% and a correlation of 98% with SD (very good fit with SD); but its FD-FFT results using strain*viscosity are: FPG=35%, Carbs=54%, K-steps=11% and a correlation of 7% with SD which does not fit with SD at all.

(3) From Figure 2 in the second case of Paper No. 677, CVD risk vs. eAG, BW, Food, its SD-VGT results are: eAG=36%, BW=34%, Food=30%; its FD-FFT results using strain*stress are: eAG=38%, BW=34%, Food=28% and a correlation of 100% with SD, almost a perfect fit with SD; but its FD-FFT results using strain*viscosity are: eAG=31%, BW=23%, Food=46% and a correlation of -78% with SD which does not fit with SD at all.

(4) From Figure 3 in the third case of Paper No. 680, Longevity vs. CVD, CKD, T2D, its SD-VGT results are CVD=32%, CKD=38%, T2D=30%; its FD-FFT results using strain*stress are: CVD=29%, CKD=44%, T2D=27% and a correlation of 99% with SD which fits with SD very well but its FD-FFT results using strain*viscosity are: CVD=31%, CKD=46%, T2D=23% and a correlation of 99% with SD which also fits with SD very well. Please note that the longevity case has an equal level of results fit. The reason for these two equal values of highly correlated FD-FFT energies with SD-VGT is that these 3 variables of longevity (1 output), CVD risk, and CKD risk (2 inputs) are developed using the same metabolism index (MI) model with highly similar inputs and equations.

This particular paper has utilized three papers, No. 680, No. 677, and No.676, as the data source and SD energy results for the hybrid model result comparison. In conclusion, the author has identified that the hybrid model of SD-VGT and FD-FFT using the "strain*stress" variable has offered better-fit results in comparison with the counterpart SD-VGT results than using the "strain*viscosity" variable. With this expectation developed from his past observations from 90+ medical research exercises, he can make a solid prediction before performing the analysis that the (strain*stress) variable would offer a better-fit FD-FFT energy result than the (strain*viscosity) variable in comparison to the SD-VGT energy result. However, the FD-FFT of (strain*viscosity) variable lacks the necessary component of strain change rate, i.e. dε/dt; therefore, it does not include sufficient influences from the "time-dependent" strain characteristics, i.e. medical symptoms fluctuation.

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.

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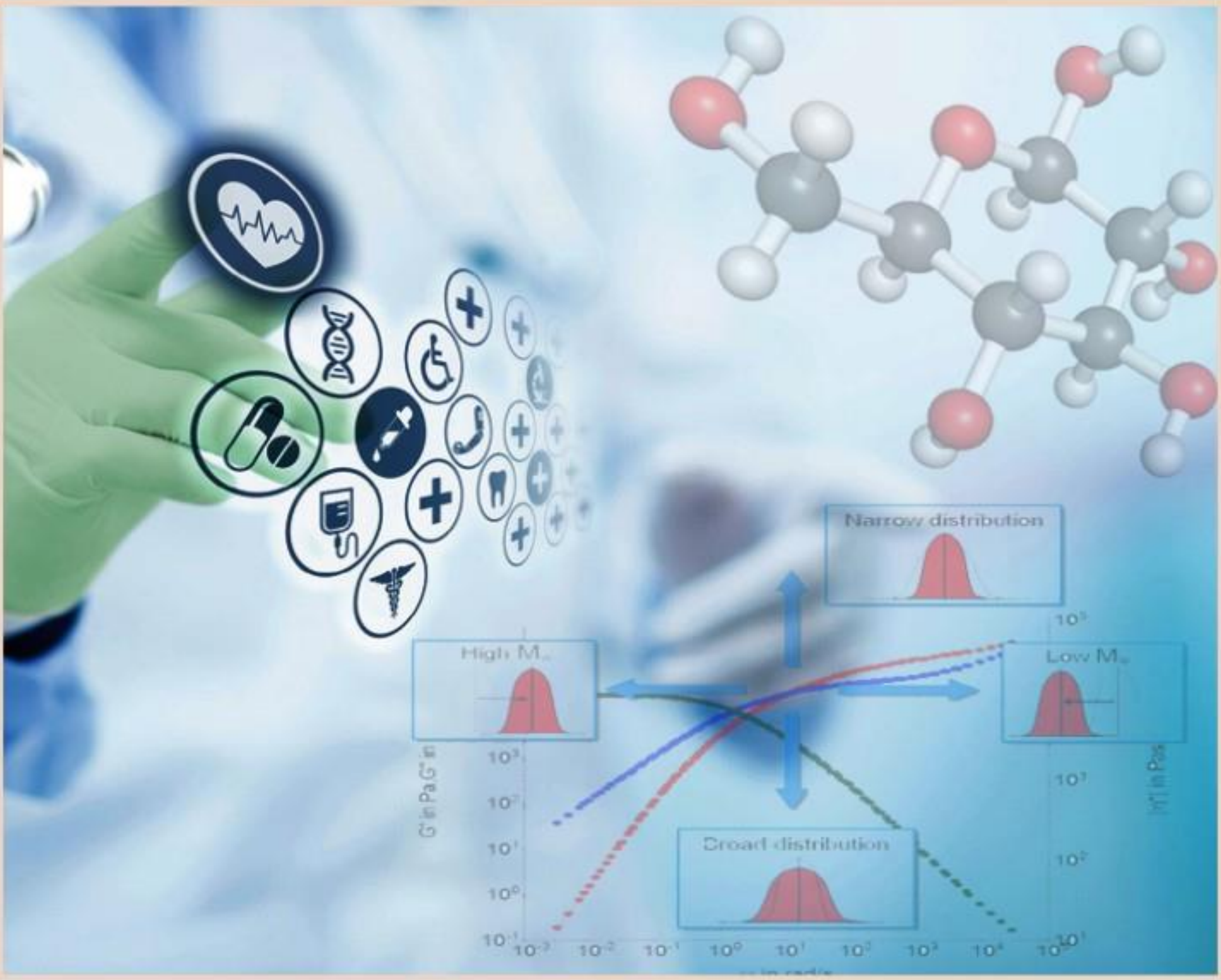
Special Issue | Issue No. 5 **The GH-Method**

Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

Gerald C. Hsu



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