The GH-Method

Viscoelastic and Viscoplastic Glucose Theory (VGT #104): Estimating Associated Energy in Time-Domain, Space-Domain, and Frequency-Domain by Applying Concepts of Statistics Correlation, Wave Theory & Frequency-Domain Analysis, Viscoelasticity & Plasticity Theory for Studying the Relationship of Fasting Plasma Glucose (FPG) versus Body Weight (BW), Body Temperature (BT), and Finger Oxygen Level (SPO2) Over a Short Time Period of 11 Months from 8/8/2021 to 6/25/2022 Based on the GH-Method: Math-Physical Medicine (No. 694)

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Note: This is an enhanced version of Paper No. 602 (VGT #23).

Keywords: Viscoelastic; Viscoplastic; Carbohydrates; Sugar; Walking k-steps; Body weight; Body temperature; Postprandial plasma glucose; Fasting plasma glucose; Type 2 diabetes; Fast Fourier transform

Abbreviations: BW: body weight; BT: body temperature; 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

The author applies theories of viscoelasticity and viscoplasticity from engineering to conduct his biomedical research on the relationship between output biomarkers of finger-pierced fasting plasma glucose (FPG) versus three input biomarkers of body weight in the early morning (BW), body temperature in the early morning (BT), and finger oxygen SPO2 % level in the early morning (O2).

The first step is to estimate three time-domain (TD) energies associated with BW, BT, and O2 by calculating 3 squared input values, i.e. squared BW, squared BT, and squared O2. In basic physics, it has stated that "the energy carried by a wave is directly proportional to the square of wave's amplitude". Second, he applies the viscoelastic or viscoplastic glucose theory (VGT) to construct a set of three space-domain (SD) stress-strain curves and then by calculating the enclosed areas of these 3 curves to obtain their three respective SD energies. Third, he then utilizes a newly-defined variable of (strain * stress) from SD to go through the fast Fourier transform operation (FFT) and calculate this new variable curve's enclosed area in the frequency-domain (FD) as their three respective FD energies.

During the COVID-19 pandemic period, out of his concerns about viral infection and its impact on his respiratory system, he started to measure his daily body temperature on 10/1/2020 and his daily finger O2 % on 8/8/2021. To compare the moving trend of these two new biomarkers, he decided to utilize the 90-day moving average method. Due to the reality of shorter time durations for both BT (18 months from 1/1/21 to 6/25/22) and O2 (10 months from 9/1/21 to 6/25/22), therefore, their correlations in TD are FPG vs. BT = 59% and FPG vs. O2 = 35%, while his FPG vs. BW = 84% over a much

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longer period of 8.5 years from 1/1/14 to 6/25/22. Please note that the correlation of FPG versus BW over the same short period of 11 months is a very low 20% which explains the data sensitivity of using the statistics method. Therefore, the findings outlined in this particular article are only "preliminary findings". In the future, after collecting much longer period data of his BT and O2, the author will revisit and re-verify this research subject and then hopefully draw some better and more accurate conclusions.

The following two generalized equations from viscoelasticity or viscoplasticity are utilized to study the stress-strain relationship in this case. Here, he wants to use the strain rate multiplied with the viscosity factor as the stress component:

Strain
= ε
= individual output FPG biomarker value at present time

Stress
= σ
= η * ($d\varepsilon/dt$)
= η * (d-strain/d-time)
= (viscosity factor η, i.e. BW, BT, O2) / (normalization factor) * (output biomarker at present time - output biomarker at previous time)

In this study he has chosen two sets of normalization factors". The first set uses the "break-even line of healthy vs. unhealthy" for BW = 170 lb., BT = 99 degrees °F, O2 = 95 %. The second set uses "1" as the normalization factor, i.e, uses their measured data of BW, BT, and O2 without any normalization.

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

2. METHODS

2.1 Brief introduction of math-physical medicine (MPM) research

The author has collected 3+ million data regarding his health condition and lifestyle details over the past 13 years. He spent the entire year of 2014 developing a metabolism index (MI) model using topology concept, nonlinear algebra, algebraic geometry, and finite element method. This MI model contains various measured biomarkers and recorded lifestyle details along with their induced new biomedical variables and data. Detailed data of his body weight, glucose, blood pressure, heart rate, blood lipids, body temperature, and blood oxygen level, along with important lifestyle details, including diet, exercise, sleep, stress, water intake, and daily life routines are included in his MI database. In addition, these lifestyle details also include some lifetime bad habits and environmental exposures. Luckily, the author has none of these lifetime bad habits and also with a very low degree of exposure from environmental toxic factors. His developed MI model has a total of 10 categories covering approximately 500 detailed elements that constitute his defined "metabolism model" which are the building blocks or root causes for diabetes and other chronic disease complications, including but not limited to cardiovascular disease (CVD), chronic heart disease (CHD), stroke, chronic kidney disease (CKD), diabetic retinopathy (DR), neuropathy, foot ulcer, and hypothyroidism. The end result of the MI development work is a combined MI value within any selected time period with 73.5% as its dividing line between a healthy and unhealthy state. The MI serves as the foundation to many of his follow-up medical research work.

During the period from 2015 to 2017, he focused his research on type 2 diabetes (T2D), especially glucoses, including fasting plasma glucose (FPG), postprandial plasma glucose (PPG), estimated average glucose (eAG), and hemoglobin A1C (HbA1C). During the following period from 2018 to 2022, he concentrated on researching medical complications resulting from diabetes, chronic diseases, and metabolic disorders which include heart problems, stroke, kidney problems, retinopathy, neuropathy, foot ulcer, diabetic skin fungal infection, hypothyroidism, and diabetic constipation, cancer, dementia, and geriatrics (longevity). He has also developed a few mathematical risk models to calculate the probability

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percentages of developing various diabetic complications.

From his previous medical research work, he has identified and learned that those associated energy of hyperglycemia conditions are the primary source of causing many diabetic complications which lead to final death. Therefore, a thorough knowledge of these biophysical energies is very important for achieving a better understanding of dangerous medical complications.

In addition, he has also identified his FPG level in the early morning serves as a clear indicator of the overall health condition of his pancreatic beta cells as well as functions as the baseline of his predicted postprandial plasma glucose (PPG) value.

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

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

What are elastic materials?

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

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

What are viscous materials?

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

What is viscoelastic?

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

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

Elastic behavior versus viscoelastic behavior

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

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

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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.

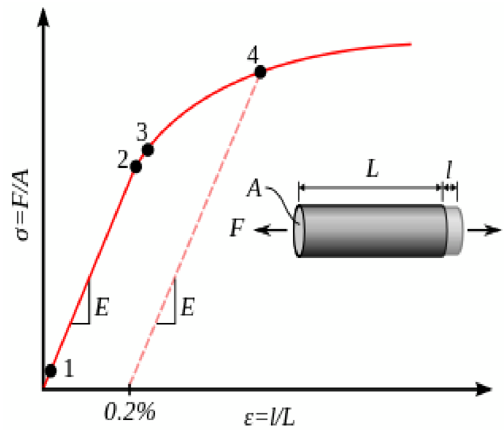
In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic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

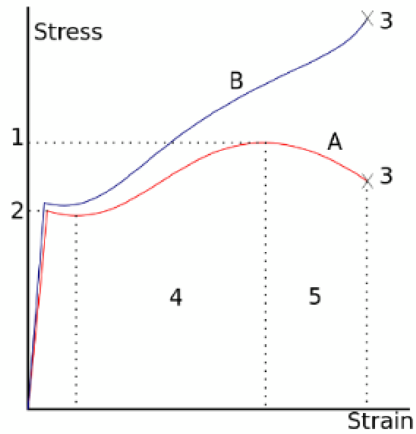
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

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

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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).

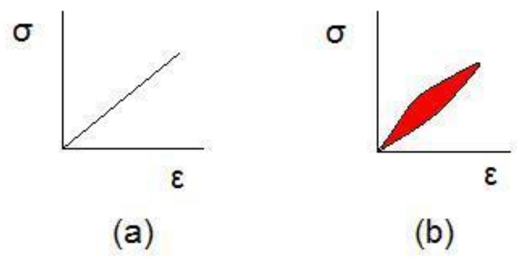
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit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

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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.

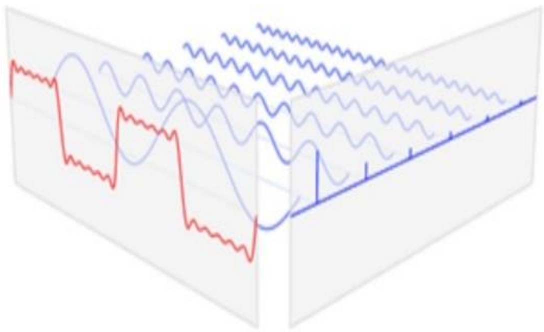
Medical analogy: In viscoelastic or viscoplastic analysis, the stress component equals the strain change rate of time multiplying with the viscosity factor, or

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
= $\oint \sigma d\varepsilon$

2.3 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

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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 for 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 which 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 displays a data table and a table of ranges for SpO2%, pulse rate, and body temperature.

Figure 2 shows the TD comparisons between his FOG versus body weight and finger O2 level.

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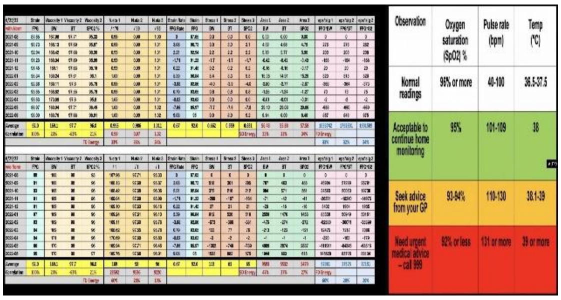

Observation	Oxygen saturation (SpO2) %	Pulse rate (bpm)	Temp (°C)
Normal readings	95% or more	40-100	36.5-37.5
Acceptable to continue home monitoring	95%	101-109	38
Seek advice from your GP	93-94%	110-130	38.1-39
Need urgent medical advice - call 999	92% or less	131 or more	39 or more

Figure 1: Data table and table of ranges for SpO2%, pulse rate, and body temperature.

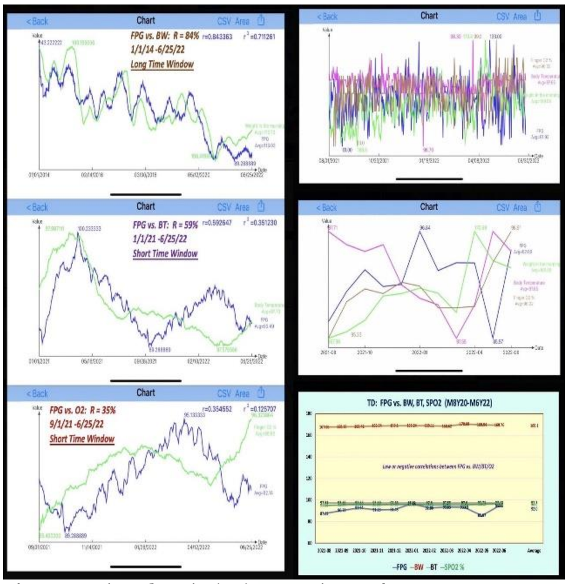

Figure 2: Time-domain (TD) comparisons of FPG versus BW, BT, and O2 from 8/1/21 to 6/25/22 and 3 correlations.

Figure 3 depicts the SD energy comparisons.

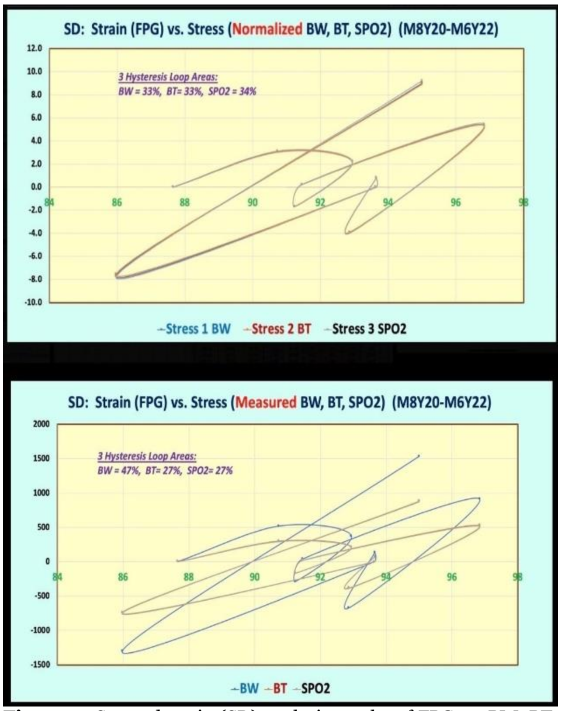

Figure 3: Space-domain (SD) analysis results of FPG vs. BW, BT, O2.

Figure 4 reflects the FD energy comparisons.

Figure 4: Frequency-domain (FD) analysis results of FPG vs. BW, BT, O2.

Figure 5 illustrates the energy comparison among TD, SD, and FD results.

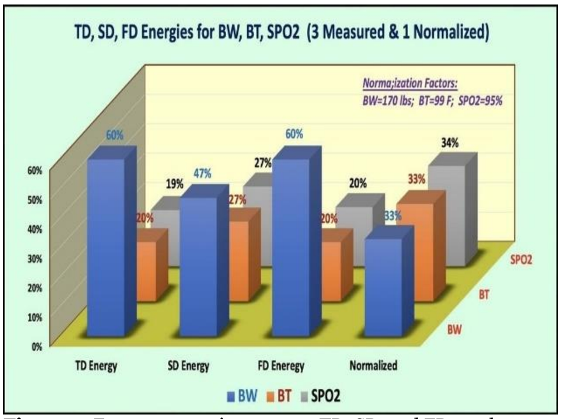

Figure 5: Energy comparison among TD, SD, and FD results.

4. CONCLUSION

In summary, the following four observations outline the specific findings from each of these 3 domains.

(1) His TD energy ratio from normalized case is BW(33%) : BT (33%) : O2(34%); and from measured case is BW(60%) : BT (20%) : O2(20%).

(2) His SD energy ratio from normalized case is BW(33%) : BT (33%) : O2(34%); and from measured case is BW(47%) : BT (27%) : O2(27%).

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(3) His FD energy ratio from normalized case is BW(33%) : BT (33%) : O2(34%); and from measured case is BW(60%) : BT (20%) : O2(20%).

(4) In summary, all of the normalized cases are having energy ratios of BW(33%) : BT (33%) : O2 (34%). For measures cases, the TD and FD energy ratios are BW(60%) : BT (20%) : O2(20%) while the SD energy ratio is BW(47%) : BT (27%) : O2(27%). For 3 measured cases, the BW has the highest contribution which resulted from the BW value (average 169 lb.) being higher than both values of BT (average 97.7 degrees °F) and O2 (average 96%). Incidentally, BT values and O2 values are very close to each other which are within the range of 95 to 99. The above description also explains why the normalized energy ratios have the same ratio pattern of 33%:33%:34%.

There are two special conclusions observed from this study. First, from measured cases, it seems that body weight has strong influences on FPG than both body temperature and finger oxygen. However, this conclusion seems to be twisted by the much shorter period of data collection with lower correlations for both BT (18 months & R=59%) and O2 (10 months & R=35%). On the contrary, BW has a data collection period of 8.5 years with R=84% with FPG. Second, the normalization process using these selected normalization factors, i.e. 170 lb. for BW, 99-degree °F for BT, and 95% for O2, would create an even ratio of averaged stresses, i.e. 33%, 33%, 33% which result in an evenly distributed energy levels as well.

5. 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.

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

To read more of the author's published VGT or FD analysis results on medical applications, please locate them through three published special editions from the following three specific journals:

(1) Special Issue. The GH-Method. (https://www.theghmethod.com)

(2) Journal of Applied Material Science & Engineering Research (contact: Catherine)

(3) Advances in Bioengineering and Biomedical Science Research (contact: Sonny Hazi).

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Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

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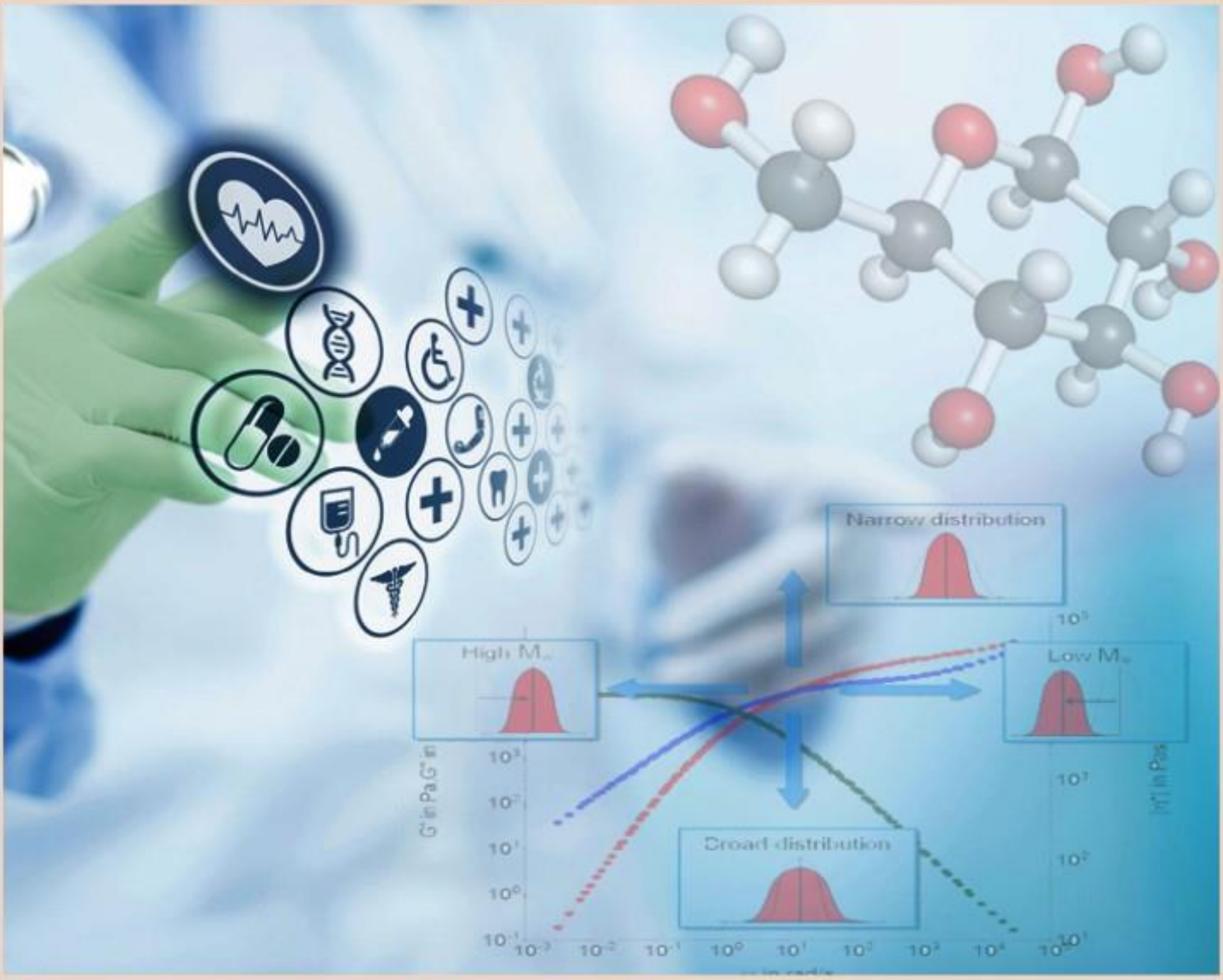

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