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Viscoelastic or Viscoplastic Glucose Theory (VGT #103): Applying the Viscoelasticity and Viscoplasticity Theory, Wave Theory, and Frequency-Domain Analysis to Study Both HbA1C versus Carbs/Sugar of Type 2 Diabetes and Behavior Symptoms versus Behavior Causes of Borderline Personality Disorder Based on GH-Method: Math-Physical Medicine (No. 693)

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Note: This article is an enhanced version of Paper No. 591 (VGT #12).

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

Abbreviations: BPD: borderline personality disorder; 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

This article focuses on various causes (behavior stimulators) and abnormal psychological symptoms of a hypothetical patient with borderline personality disorder (BPD) during a long period of 13 years from Y2010 to Y2022. The author has self-studied abnormal psychology since 2002 and also established five psychotherapy centers to take care of 200+ abused women and abandoned children during the period from 2006 to 2010. Due to professional ethics and practical concerns about patients confidentiality, he cannot reveal any of their identities and stories, or use any of those patients information. Therefore, in this article, both BPD symptoms and BPD causes are based on his self-learned knowledge of abnormal psychology and his observed behaviors of BPD patients in his psychotherapy centers and then synthesized them into this hypothetical BPD case.

Psychology is an empirical science that is easier to describe in words about stressors or stimulators (i.e. causes), behaviors, or reactions (i.e. symptoms). However, it is much more difficult to describe them in numbers or equations to have a deeper and quantitative understanding of psychological behavior patterns. That is why most psychological research works are, at best, based on statistics only, and not based on any other branches of natural science, such as physics and mathematics.

During the period from 2002 to 2010, he has read approximately 100+ abnormal psychology books and 500+ clinical reports. Based on his learning, he tried to develop some “scientific-based equations” to have a quantitative and high-precision approach to researching abnormal psychology. Here, the word “scientific” means observing physical phenomena, applying physics principles, deriving mathematical equations, building engineering modeling, and utilizing computer and artificial intelligence tools, not relying on statistics alone. However, it was still very difficult for him to collect and utilize data collected from patients with Personality Disorder (PD) without breaching professional ethics and patient confidentiality. He then gave up his original idea of developing a

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math-physical-based research approach (MPM) for the psychology field.

In the summer of 2010, when his health conditions became life-threatening due to his severe type 2 diabetes (T2D) conditions, he ceased his operations and studies of psychology. Instead, he launched his GH-Method: math-Physical medicine (MPM) methodology for research on internal medicine subjects, including diabetes, metabolism, endocrinology, food nutrition, chronic diseases, and multiple complications to save his own life. To date, he has written and published nearly 700 medical papers using this MPM method. This particular paper is one of his few attempts to apply his developed MPM methodology to the abnormal psychology field of BPD. The author hopes to continue his psychological research by using more of the MPM approach. He appreciates the invaluable inputs, comments, criticisms, and suggestions from his colleagues regarding the area of abnormal psychology.

Although this article mainly focused on a psychological case study with hypothetical data of a BPD patient, it is also complemented with collected data from a real T2D patient (his own data). The reader can assume that this study is regarding a hypothetical patient who has both T2D and BPD conditions. Therefore the results of this study can be served as an example to compare both physiological and psychological diseases oinany hypothetical or real patients.

The author studied both strengths of materials and the theory of elasticity from undergraduate courses at the University of Iowa. He also conducted research work to earn a Master's degree in Biomechanics under Professor James Andrews at UI. He still remembers that he used a model with both spring and dashpot (similar to an oil-filled shock absorber) to simulate the behaviors of human bone (similar to spring), muscle and tendon (similar to dashpot) in order to study the interactions between US soldiers and their M16 automatic weapon during Vietnam war. Later on, 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 structural elements. At the same time, he took some other graduate courses at MIT including thermodynamics and fluid dynamics which dealt with time-dependent situations.

Since 1970, biomechanics field has made some visible advancements in a few application areas, especially body parts and tissues of human limb which posses both elastic & viscoelastic characteristics, such as bone, muscle, cartilage, tendon (connect bone to muscle), ligament (connect bone to bone), fascia and skin. For example, the night splint dorsiflexes forefoot on rear foot increasing plantar fascia tension to offer stress-relaxation of plantar fascia pain. This muscles and tendons connecting model of lower-leg and foot is a kind of viscoelastic problem.

When we deal with internal organs, it is not as easy and straightforward as bones and muscles. For example, we cannot easily conduct live-body experiments in a medical laboratory in order to obtain some accurate and useful measurements of biomaterial properties. Although blood itself is a viscous material which viscosity factor may sit between water and honey, syrup or gel. But, the author's research subject is related to the "glucose" compound inside the blood vessel, i.e. the sugar amount inside of blood or carried by blood cells, not the blood itself. Therefore, it is near impossible to measure material geometry or figure out the engineering properties of "glucose". The best way he can do this is to apply the concept of elasticity, plasticity, viscoelasticity, and viscoplasticity to construct an "analogy model" of glucose to study the complex biophysical behaviors of glucose which are both nonlinear and dynamic, i.e. time-dependent.

The author's academic background covers mathematics, physics, and various engineering disciplines, but excluding biology, chemistry or medicine. As a result, he can only investigate his observed biophysical phenomena to make meaningful biomedical interpretations and then try to derive some useful conclusions or hints for healthcare purposes using his ready-learned math-physical knowledge from his 39 years of college-level curriculums and self-studies oin10 different academic disciplines.

Based on other medical research papers, for example, people without diabetes (normal case) have post-meal glucose (PPG) waveforms within a range between 80 mg/dL (start and end) and 120 mg/dL (peak), and HbA1C is 4%-5.6%. For pre-diabetes patients, their PPG waveforms range between 100 mg/dL (start and end) and 180 mg/dL (peak), and HbA1C is 5.7%-6.4%. For diabetes patients who has PPG range between 140 mg/dL-180 mg/dL (starting), 360 mg/dL (peak at 1-hour), and 330 mg/dL (ending at 3-hours) or 270 mg/dL (if ending at 5-hours), and HbA1C above 6.5%.

Currently, many people live a sedentary lifestyle and lack sufficient exercise to burn off their influx of energy which pushes them to become either overweight or obese conditions. Being overweight and obese leads to many chronic diseases, including diabetes, heart attacks, and cancers. For example, there are ~85% of worldwide diabetes patients are overweight, and there are ~75% of patients with cardiac illnesses or surgeries have diabetes conditions. In addition, many types of processed food contain certain unhealthy ingredients, and harmful chemicals from our surrounding environment that are toxic to the bodies, which lead to the development of many other deadly diseases, including a variety of cancers.

The author has already investigated glucose behaviors over the past 8 years using linear elasticity theory and nonlinear plasticity theory and has written several hundred medical articles. In December of 2021, Professor Norman Jones, his advisor at MIT, wrote an email to him. He said,"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 emphasised the time-dependence of various behaviours in the body. Just a thought." His suggestion has triggered the author's interest and desire to investigate further more about glucose behaviors using the viscosity theory. Since then, he has written 100+ medical papers using these viscoplastic or viscoplastic analysis tools.

He applies the following equations of space-domain (SD) VGT tool for this combined T2D & BPD study:

Stress σ
$= \eta * (d\varepsilon/dt)$

For T2D:

Stress
= viscosity factor of carbs/sugar grams * (present A1C - previous A1C)

For BPD:

Stress
= viscosity factor with a selected multiplier * (present symptom score - previous symptom score)

Strain ε
= present value of T2D-A1C value or BPD-symptom score

His research effort in this combined study includes the following 3 major parts, time-domain (TD) analysis, SD analysis, and frequency-domain (FD) analysis:

First, he investigates his collected time-domain data using the magnitude of the squared strain to indicate the relative strength of TD energy. Second, he investigates his collected data via the SD-VGT tool using theories of viscoelasticity and viscoplasticity to draw the stress-strain curve, i.e. hysteresis loop area, for his SD-energy estimation. Third, he investigates his calculated data of SD area (i.e. enclosed area of the stress-strain curve from SD) and then applies the wave theory and frequency-domain fast Fourier transform (FD-FFT) operation to estimate his FD-energy.

The analogy between engineering and medicine is twofold. First, the force or stress in physics and engineering corresponds to the influential force or cause on our body for pushing glucose upward or dragging glucose downward due to the combined effect of carbohydrates and sugar intake amount and post-meal walking exercise. This force or cause has no difference between elastic and plastic. Second, the deformation or strain in physics and engineering corresponds to the actual glucose level in medicine. The strain, symptom of glucose level, indeed has a noticeable difference between elastic case and plastic case. For the BPD case, there is no elastic situation, i.e. return to its original healthy state, but only a plastic situation that has permanent damage from the viewpoint of symptoms.

However, the medical field is still quite different from the engineering field, where engineering materials such as steel, copper, concrete, and aluminum are inorganic materials 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 body cells, and mind have organic material and go through many distinct stages over their lifespans, such as birth, split, growth, mutation, development, duplication, repair, sickness, and death. Therefore, the biomedical properties are "moving targets" which vary with the individual person, the severity of diabetes, and different selected time windows. In other words, they are both time-dependent and specimen-dependent. Because of these fundamental differences, calculations of a cross-section of subject and calculation of bending moment of resistance, or shape-factors in solid mechanics are not applicable in this biomedical analogy study. The most important thing is that applying the concept of elasticity, plasticity, viscoelasticity, or viscoplasticity in understanding the biophysical phenomena quantitatively is extremely useful for exploring deeper insights into predicting both normal and abnormal glucose behaviors and borderline personality disorder.

Similar to diabetes patients, abnormal BPD psychological patients, their symptoms and causes are also both time-dependent and long-lasting (not easy to modify within a short period).

Viscoelasticity and viscoplasticity

For readers in the medical or psychology field who do not have sufficient background in physics, engineering, and mathematics, the author decides to describe the VGT approach step-by-step in the English language instead of equations or formulas.

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 tperiod 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 considered as the degrees of influence on output by inputs.

The seventh step is to define a "hybrid input variable" by using "strain*stress" from SD as a newly defined variable for his follow-on calculations of another estimated energy. The eighth step is to present these hybrid models' results of (strain*stress) 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 "strain*stress" in FD against the VGT results in SD.

Energy theory

After declaring the analogy of elasticity, plasticity, viscoelasticity, viscoplasticity, the energy theory and wave theory in physics can be brought into context. The human body and organs are composed of different organic cells that require energy infusion from glucose carried by red blood cells; the stored glucose can then be used for labor work or exercise. According to a physics book, energies associated with the glucose waves are proportional to the square of the glucose amplitude. After eating and exercising, there are some "left-over" or "residual" energies from elevated glucoses still circulating inside the human body via blood which can impact all of the internal organs to cause different degrees of damage, i.e. diabetic complications.

BPD patients are similar to diabetes patients who had suffered from long-term abuses, mostly from people who suppose to love them. Even psychotherapy consultations will not be able to "cure or heal" them, at most to be able to put their emotions under control, very similar to the diabetes case. Each time of a BPD patient's emotional outburst has generated "excessive energy" which hurts the patient's psychological health. This similarity can be observed from the hyperglycemia of a diabetes patient from consuming high carbs/sugar meals which generates "excessive and residual energy" to hurt the patient's overall physical health.

The author has applied Fast Fourier Transform (FFT) operations to convert the glucose wave from a time-domain into a frequency-domain. The y-axis amplitude values in the frequency-domain indicate the proportional energy levels associated with each different frequency component of glucose occurrence. Actually, both glucose value (strain amplitude in time-domain) and glucose fluctuation rate (the strain rate and strain frequency) are influencing the energy level (the Y-amplitude in frequency domain).

To offer a simpler 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 concept of elasticity, plasticity, viscoelasticity &, viscoplasticity, wave theory, and FD analysis method from the disciplines of engineering and physics in the method section.

2. METHODS

2.1 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.

2.2 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.

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.

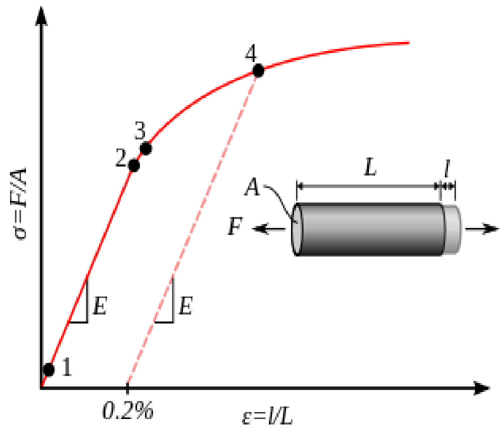
In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic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

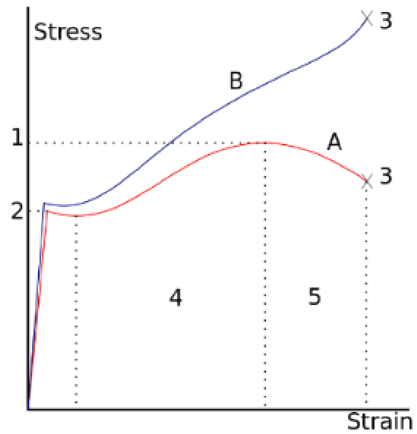
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

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.

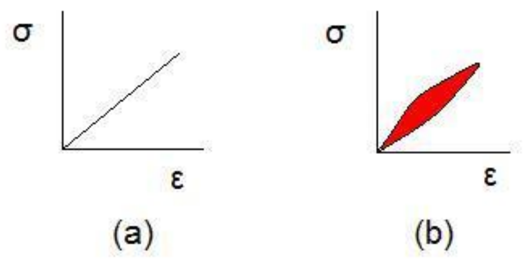
Cracking occurs when the strain is applied quickly and outside of the elastic limit. Ligaments and tendons are viscoelastic, so the extent of the potential damage to them depends both on the rate of the change of their length as well as on the force applied.

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.

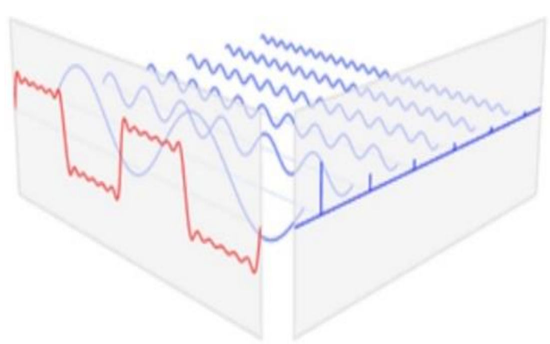
Medical analogy: In viscoelastic or viscoplastic analysis, the stress component equals the strain change rate of time multiplying with the viscosity factor, or

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
= $\oint \sigma d\varepsilon$

2.3 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 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 shows the general causes and symptoms of BPD.

Figure 1: Causes and symptoms of BPD.

Figure 2 displays the data table of this analysis.

6/22/22		eAG / 17	eta	Strain Rate	A1C	dA1C/dt * eta	Area
T2D	eAG	HbA1C	Carbs	A1C Rate	Strain	Stress	Area
Y2010	200	11.8	100.0	0.0	11.8	0.0	0.0
Y2011	170	10.0	95.0	-1.8	10.0	-167.6	147.9
Y2012	158	9.3	88.0	-0.7	9.3	-62.1	81.1
Y2013	133	7.8	80.0	-1.5	7.8	-121.3	139.1
Y2014	135	7.9	72.0	0.1	7.9	8.5	-6.6
Y2015	129	7.7	14.3	-0.2	7.7	-3.3	-0.6
Y2016	119	7.0	15.6	-0.6	7.0	-10.0	4.3
Y2017	117	6.9	14.5	-0.1	6.9	-1.6	0.6
Y2018	116	6.9	15.8	-0.1	6.9	-0.9	0.1
Y2019	114	6.7	13.2	-0.1	6.7	-1.5	0.1
Y2020	106	6.3	13.7	-0.4	6.3	-5.7	1.5
Y2021	105	6.1	12.8	-0.2	6.1	-2.3	0.7
Y2022	105	6.2	10.5	0.0	6.2	0.3	0.0
Avg / Sum	131.3	7.7	42.0	-0.4	7.7	-28.3	368
Correlation	100%		88%				
TD Energy	Avg A1C**2	60				FD Energy	40557
					Y10-Y14 Area	362	98%

6/22/22	Scale		eta		Strain Rate	Symp*1	dSymp/dt * eta	Area
BPD	Symtom	Symptom*2	Cause	Cause*5	Symp Rate	Strain	Stress	Area
Y2010	5	10.0	10.0	50	0.0	10.0	0.0	0.0
Y2011	5	10.0	10.0	50	0.0	10.0	0.0	0.0
Y2012	5	10.0	9.0	45	0.0	10.0	0.0	0.0
Y2013	4	8.0	9.0	45	-2.0	8.0	-90.0	90.0
Y2014	3	6.0	8.0	40	-2.0	6.0	-80.0	170.0
Y2015	3	6.0	8.0	40	0.0	6.0	0.0	0.0
Y2016	3	6.0	7.0	35	0.0	6.0	0.0	0.0
Y2017	3	6.0	7.0	35	0.0	6.0	0.0	0.0
Y2018	3	6.0	6.0	30	0.0	6.0	0.0	0.0
Y2019	4	8.0	6.0	30	2.0	8.0	60.0	60.0
Y2020	6	12.0	7.0	35	4.0	12.0	140.0	400.0
Y2021	7	14.0	8.0	40	2.0	14.0	80.0	220.0
Y2022	7	14.0	9.0	45	0.0	14.0	0.0	0.0
Avg / Sum	4.5	8.9	8.0	40.0	0.3	8.9	8.5	940
Correlation	100%		41%					
TD Energy	Avg Symp**2	80					FD Energy	196116
						Y10-Y14 Area	620	66%

Figure 2: Data table.

Figure 3 depicts the TD of squared-strain energy.

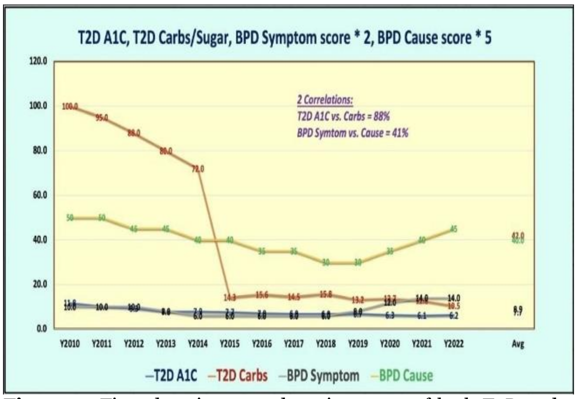


Figure 3: Time-domain squared strain energy of both T2D and BPD.

Figure 4 reflects SD-VGT energy.

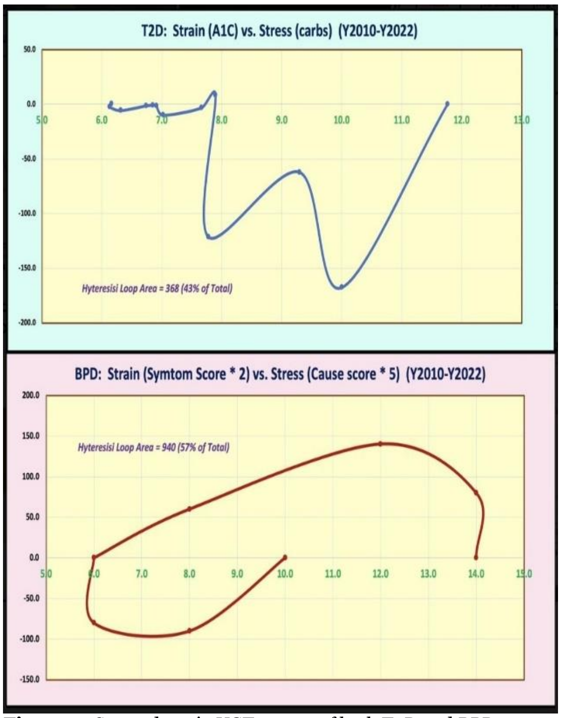


Figure 4: Space-domain VGT energy of both T2D and BPD.

Figure 5 depicts FD-FFT energy.

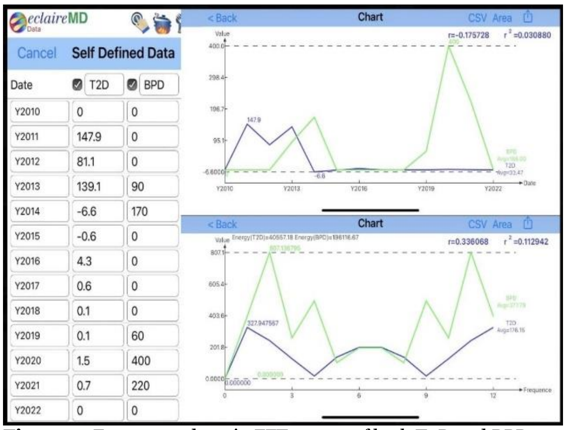


Figure 5: Frequency-domain FFT energy of both T2D and BPD.

Figure 6 illustrates the comparison of results from TD energy, SD energy, and FD energy for both T2D and BPD cases, including one sub-period energy comparison.

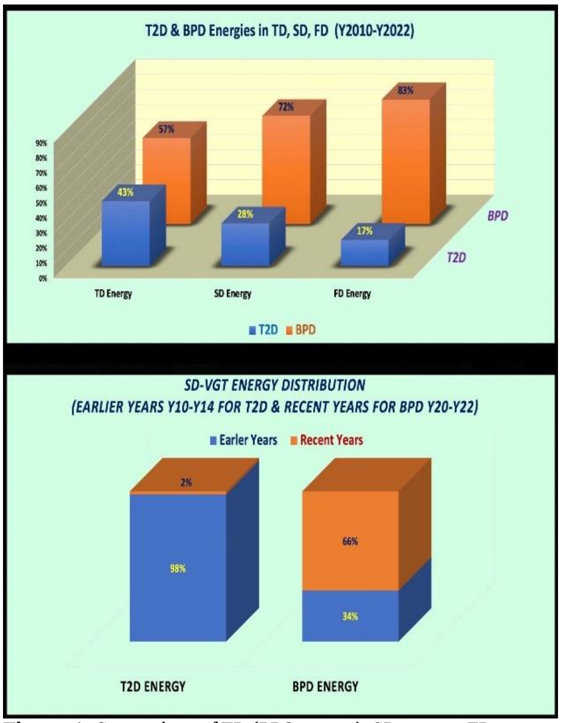


Figure 6: Comparison of TD (PPG square), SD energy, FD energy, and sub-period energy analysis.

4. CONCLUSION

In summary, there are five key observations described below:

(1) From TD energy analysis results using the squared strain as an indication of energy level, the TD energy ratio is T2D=60 (43% or 1) versus BPD=80 (57% or 1.3).

(2) From SD energy analysis results using the hysteresis loop area as an indication of energy level, the SD energy ratio is T2D=368 (28% or 1) versus BPD=940 (72% or 3.9).

(3) From FD energy analysis results using the frequency carve area as an indication of energy level, the FD energy ratio is T2D=40557 (17% or 1) versus BPD=196116 (83%or 4.8).

(4) Examination of space diagrams stress (carbs, causes) versus strain (HbA1C, symptoms), T2D and BPD have different curve patterns, but both of them have shown viscoplastic behaviors, e.g. time-dependency, non-convergence between the initial period data and ending period data, i.e. there is a gap between the starting point and ending point, and the existence of hysteresis loops (energy generation or loss through loading and unloading process of stimulations). Like a movie film, these two SD-VGT stress-strain curves have shown how this hypothetical patient has been fighting against type 2 diabetes and also coping with borderline personality disorder within the same period.

(5) An interesting finding from the sub-periods SD-VGT energy analysis results is that the earlier sub-period of Y2010-Y214 has occupied 98% of the total T2D energy while the recent COVID period of Y2020-Y2022 has occupied 66% of the total BPD energy. This explains that his first 5 years of energy contribute almost the entire damage to his organs due to diabetes, and his recent 3 years of COVID quarantine period contribute 2/3 of his total psychological energy during the past 13 years. To examine the details of both glucoses of T2D and symptoms of BPD, he notices that the T2D patient's glucose improves while the BPD patient's symptoms become worse. The isolated peaceful and non-traveling lifestyle has contributed to better glucoses for the T2D conditions, but the fear of COVID -19 infection and loneliness associated with the quarantined lifestyle have contributed to the worsening symptoms of BPD.

Both diabetes conditions control and BPD emotional control are difficult tasks since in addition to the individual domain-know-how of medicine and psychology, this complex biophysical behaviors of glucose and multi-phased borderline psychological behaviors require a deeper knowledge of physics, engineering, and mathematics, more than depending on biology, chemistry, and statistics alone.

The case of BPD data pattern is indeed following the natural law of physics which is similar to the case of T2D data pattern. From this study, we can see that the physical theories and engineering models are suitable tools for conducting both medical research work and psychological research work, except the data collection of psychotherapy is much more difficult for the author.

5. ACKNOWLEDGMENT

Without Professor Norman Jones at MIT as his academic advisor, the author would not be able to conduct this particular research work and also published nearly 700 medical research papers. The author has never forgotten his advice to him that he should always focus on and enhance his basic strength on foundations, such as mathematics and physics, in order to make further improvement and advancement. Professor Jones has also provided him a personal example of doing outstanding teaching and research job with an excellent work attitude, extreme dedication, and ultimate commitment on advancing both science and engineering.

6. 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.

To read more of the author's published VGT or FD analysis results on medical applications, here are three published special editions from the following 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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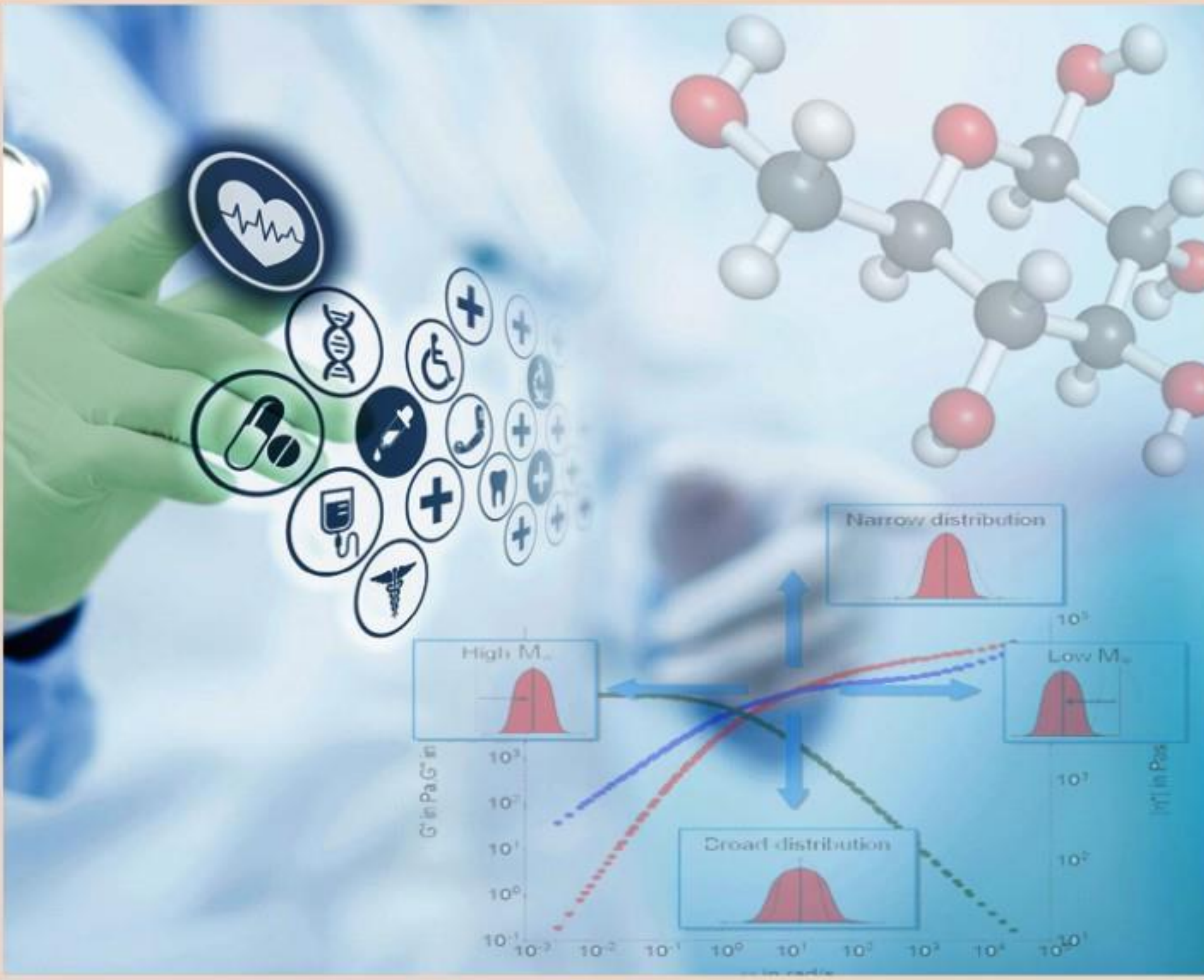

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