Viscoelastic or Viscoplastic Glucose Theory (VGT #91): Using Time-Domain, Space-Domain, and Frequency-Domain Analysis Methods to Compare the Results of Longevity Versus Cardiovascular Disease, Chronic Kidney Disease, and Type 2 Diabetes Conditions over Two Sub-Periods, Y12-Y14 Versus Y15-Y22, Based on GH-Method: Math-Physical Medicine (No. 681)

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Abstract

The author is a mathematician and 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 600+ research papers in various journals using different math-physical medicine methodologies (MPM).

Beginning with paper No. 578 dated 1/8/2022, he has written 80+ medical papers and 4 economics papers using viscoelasticity and viscoplasticity theories (VGT) tools from physics and engineering disciplines. These papers aim to explore some hidden physical behaviors and provide a deeper quantitative understanding 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, and certain medical complications, such as heart attacks, stroke, cancers, dementia, and even longevity concerns. He has noticed that most medical subjects with their associated data, multiple symptoms, and influential factors are *"time-dependent"* which means that **all biomedical variables change from time to time because body living cells are dynamically changing.** This is what **Professor Norman Jones**, the author's adviser at MIT, suggested to him in December 2021 and why he utilizes the VGT tools from physics and engineering to conduct his medical research work since then.

Papers No. 671 through No. 674 focused on the COVID infectious disease as the input and three key US economic measurements as the outputs. From this economics exercise, he realized that the established theory of viscoelasticity and viscoplasticity (from the physics branch of science) **should not only be limited to the scope of engineering applications.** Its ability to link certain time-dependent variables and their physical characteristics and associated energy estimation via the hysteresis loop area is **equally powerful for applications in many other research fields, such as economics and medicine.**

The author would like to **describe the essence of the VGT in 6 simple steps in plain English instead of mathematical equations** for readers who do not have an extensive academic background in engineering, physics & mathematics - an excerpt from Wikipedia is included in the Method section of this full-text article.

The first step is to collect the output data (strain or ε) on a time scale, e.g. the longevity via age difference between real biological age and estimated health age. The second step is to calculate the output change rate with time (**dε/dt**), e.g. the change rate of age difference over each year. The third step is to collect the input data (viscosity or **η**) on a time scale, e.g. cardiovascular disease (CVD) risk, chronic kidney disease (CKD) risk or type 2 diabetes (T2D) conditions. The fourth step is to calculate the time-dependent input (time-dependent stress or σ) by multiplying **dε/dt** and η together. The "**time-dependent input equation**" is "stress σ = strain change rate of dε/dt * viscosity η". The fifth step is to plot the input-output (i.e. stress-strain or cause-symp-

tom) 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 input-output curves (or hysteresis loop areas), which is also the 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.

After providing this English description, he would like to use the following re-defined **VGT equation** to address the unique **"time-dependency characteristics"** of engineering, economics, and medical variables. He can then establish the following set of **stress-strain equations** in a two-dimensional SD:

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, e.g. COVID infection case)
= 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 with the average number of viscosity or a certain established health standard, such as 120 mg/dL for glucose or 25 for BMI and 170 lbs. for his ideal body weight, 50% for risks of developing CVD or CKD, 6.0% for his "controlled HbA1C" values. Using non-normalized and originally collected data would distort the numerical comparison of the hysteresis loop areas. The 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 these originally collected variables into a set of **"dimensionless variables"** for easier numerical comparison and result interpretation.

In addition, the author decided to utilize a frequency-domain (FD) fast Fourier transform (FTT) energy analysis method on the same dataset, i.e. age difference versus CVD, CKD, and T2D. **This FD analysis selects three "newly defined" variables, i.e. (CVD risk / 50 * Age difference), (CKD risk / 50 * Age difference), and (HbA1C/6 * Age difference). Then they are transformed from TD to FD using a fast Fourier transform (FFT) operation**. A brief excerpt of "TD to FD via FFT" from Wikipedia is also included in the Methods section.

His developed equation for estimated health age is:

Estimated Health Age
= Real Biological Age *
(1+((MI-0.735)/0.735)/2)

Where MI is a daily "metabolism index" which is a combined score of 4 biomarkers of weight, glucose, blood pressure, and blood lipids along with 6 lifestyle details of food, water intake, exercise, sleep, stress, and daily life routines. Furthermore, **a positive age difference number means a shorter expected lifespan and a negative age difference number indicates a longer expected lifespan.**

In summary, there are 5 observations from this energy analysis of longevity versus CVD risk, CKD risk, and T2D conditions using three different approaches, TD-R (R means correlation), SD-VGT, and FD-FFT.

(1)   From the TD analysis of his collected data in 11 years, his **calculated correlations are longevity vs. CVD = 100%; longevity vs. CKD = 95%; longevity vs. T2D = 82%. These three correlations are ranked with the ranking order of heart attack/stroke (100%), kidney failure (95%), and diabetic complications (82%). In other words, his longevity perspectives are dependent on complications associated with arteries in the heart or brain, micro-blood vessels in kidneys, and glucose levels in the blood system throughout the body.** This ranking order makes sense based on general biomedical knowledge and his personal medical history. Detailed results from the TD analysis further indicate that **the average variable values used in TD are 4.24 for (Age difference * CKD) and 3.85 for (Age difference * CVD); 3.07 for (Age difference * T2D) which has the same ranking order as the SD and FD results described below.**
(2)   Researching the part of stress-strain variation from the SD-VGT results, we can see that his Age differences decreased from 9.6 years in 2013 (a positive age difference means a shorter expected lifespan) to -10.44 years in 2022 (a negative age difference means a longer expected lifespan). His CVD risk % decreased from

86% in Y2013 to 52% in Y2021. His CKD risk % decreased from 109% in Y2012 to 67% in Y2022. His A1C values lessened from 7.45% in Y2012 to 5.95% in Y2022. **Generally speaking, his 3 biomarkers, CVD risk, CKD risk, and T2D (A1C) conditions, along with his Age difference numbers (health age minus real age) are decreasing year after year.**

(3)   Researching the stress-strain diagrams from the VGT analysis results, the 3 waveform patterns of stress-strain curves are highly similar to each other due to the usage of identical strain change rates, i.e. the Age difference change rate. When combined with 3 different viscosities, CVD, CKD, and T2D, these 3 stress magnitudes and 3 hysteresis loop areas are somewhat different but have similar waveform patterns. The conclusive observation is that **using the SD-VGT energy method, CKD generates the highest energy level of 136 (38%), CVD produces the middle energy level of 111 (31%), and T2D creates the lowest energy level of 107 (30%). Another important SD-VGT observation is that the sub-period's energy ratios of 97 (27%) for the first 3 years of Y2012-Y2014 versus 257 (73%) for the next 8 years of Y2015-Y2022.**

(4)   Using the FD-FFT energy analysis, the results are 1622 (46%) for the case of (Age difference * CKD); 1094 (31%) for the case of (Age difference * CVD); and 795 (23%) for the case of (Age difference * T2D). The ranking order of FD-FFT results is similar to the ranking order of SD-VGT results.

(5)   Regarding the sub-period energy analysis results, **for the sub-period of Y12-Y14, the SD-VGT results** *are CKD=38%, CVD=32%, and T2D=30%. The FD-FFT results* **are CKD=39%, CVD=33%, and T2D=28% which are almost identical. For the sub-period energy analysis results**, *the Y15-Y22 SD-VGT results are CKD=39%, CVD=31%, and T2D=30%. The FD-FFT results are CKD=47%, CVD=31%, and T2D=22% which* **are quite similar to each other except that CKD is bigger and T2D is smaller.** *Generally speaking, the 2 different energy methods (SD-VGT vs. FD-FFT) for longevity have yielded similar output patterns of energy ratio between the 2 sub-periods.* **The bar chart in Figure 3 also shows graphically that the relative heights of the bars are comparable to each other between the SD-VGT method and the FD-FFT method.**

Both the SD-VGT energy tool adopted from engineering and the FD-FFT energy tool adopted from physics have yielded extremely similar results with interesting clues. They provide useful interpretation of biomedical results from this research work on longevity perspectives from CVD Risk, CKD risk, and T2D conditions. Although the author cannot precisely predict the future outlook of his lifespan, by using a scientific way (mathematics and physics) to project his longevity perspectives can provide useful guidance to achieve his ultimate goal of extended healthy life.
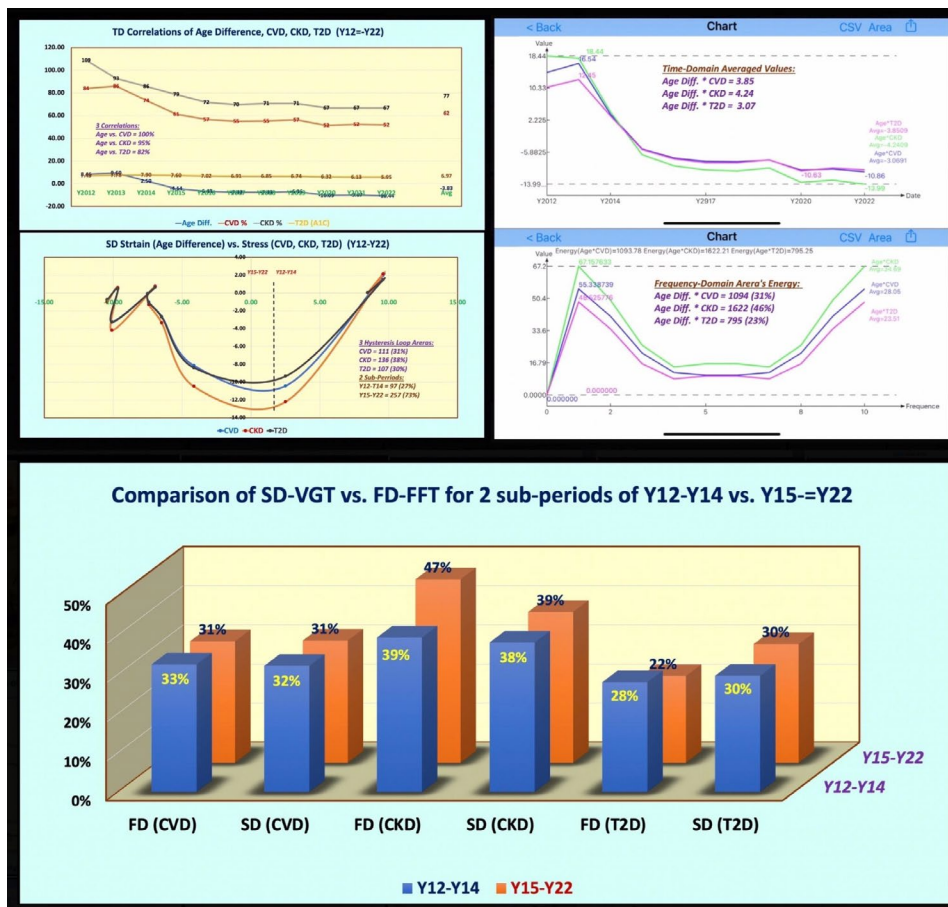
Introduction

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multiplying $d\varepsilon/dt$ and **η** together. **The "time-dependent input equation" is "stress σ = strain change rate of dε/dt * viscosity η".** 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 input-output curves (or hysteresis loop areas), which is also the 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.

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Method
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 82 biomedical research cases and 4 economics 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 condi-

tions 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.

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.

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 counterpart is "when cause or risk factors are reduced or removed, the symptoms of the certain disease would be improved or ceased".

What are Viscous Materials?
Viscosity is a measure of a fluid's resistance to flow. A fluid with large viscosity resists motion. A fluid with low viscosity flows. For example, water flows more easily than syrup because it has a lower viscosity. High viscosity materials might include honey, syrups, or gels – generally, things that resist flow. Water is a low viscosity material, as it flows readily. Viscous materials are thick, 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 temperatures, display significant viscoelastic effects. In some applications, even a small viscoelastic response can be significant.

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

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

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

The Following Brief Introductions are Excerpts from Wikipedia:

"Elasticity (Physics)
Physical property is when materials or objects return to their original shape after deformation.

In physics and materials science, **elasticity** is the ability of a body to resist a distorting influence and to return to its original size and shape when that influence or force is removed. Solid objects will deform when adequate loads are applied to them; if the material is elastic, the object will return to its initial shape and size after removal. This is in contrast to plasticity, in which the object fails to do so and instead remains in its deformed state.

Hooke's law states that the force required to deform elastic objects should be directly proportional to the distance of deformation, regardless of how large that distance becomes. This is known as perfect elasticity, in which a given object will return to its original shape no matter how strongly it is deformed. This is an ideal concept only; most materials that possess elasticity in practice remain purely elastic only up to very small deformations, after which plastic (permanent) deformation occurs.

In engineering, the elasticity of a material is quantified by the elastic modulus such as Young's modulus, bulk modulus, or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic limit or yield strength is the maximum stress that can arise before the onset of plastic deformation.

Medical Analogy: The elastic behavior analogy in medicine can be expressed by the metal rod analogy for the postprandial plasma glucose (PPG). Consuming carbohydrates and/or sugar acts like a tensile force to stretch a metal rod longer, while post-meal exercise acts like a compressive force to suppress a metal rod shorter. If lacking food consumption and exercise, the metal rod (analogy of PPG) will remain in its original length, similar to a non-diabetes person or less-severed type 2 diabetes (T2D) patient.

Plasticity (Physics)

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

In physics and materials science, **plasticity**, also known as **plastic deformation,** is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces. For example, a solid piece of metal being bent or pounded into a new shape displays plasticity as permanent changes occur within the material itself. In engineering, the transition from elastic behavior to plastic behavior is known as yielding. Plastic deformation is observed in most materials, particularly metals, soils, rocks, concrete, and foams.
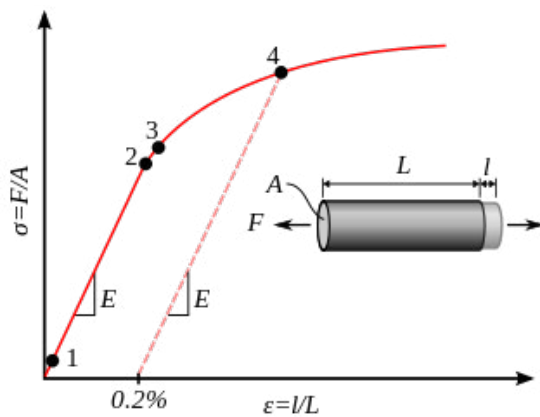
A stress-strain curve showing typical yield behavior for nonferrous alloys.

1. True elastic limit
2. Proportionality limit
3. Elastic limit
4. Offset yield strength
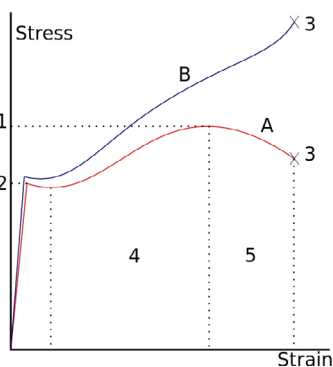
A stress strain is typical of structural steel.

• 1: Ultimate strength
• 2: Yield strength (yield point)
• 3: Rupture
• 4: Strain hardening region
• 5: Necking region
• A: Apparent stress (F/A0)
• B: Actual stress (F/A)

For many ductile metals, tensile loading applied to a sample will cause it to behave in an elastic manner. Each increment of the load is accompanied by a proportional increment in extension.

When the load is removed, the piece returns to its original size. However, once the load exceeds a threshold – the yield strength – the extension increases more rapidly than in the elastic region; now when the load is removed, some degree of the extension will remain.

Medical Analogy: A plastic behavior analogy in medicine is the PPG level of a severe T2D patient. Even consuming a smaller amount of carbs/sugar, the patient's PPG will rise sharply which cannot be brought down to a healthy level of PPG even with a significant amount of exercise. This means that the PPG level has exceeded its "elastic limit" and entered into a "plastic range".

Viscoelasticity

Property of materials with both viscous and elastic characteristics under deformation.

In materials science and continuum mechanics, viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like water, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed.

Viscoelastic materials have elements of both of these properties and, as such, exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.

In the nineteenth century, physicists such as Maxwell, Boltzmann, and Kelvin researched and experimented with the creep and recovery of glasses, metals, and rubbers. Viscoelasticity was further examined in the late twentieth century when synthetic polymers were engineered and used in a variety of applications. **Viscoelasticity calculations depend heavily on the viscosity variable, η. The inverse of η is also known as fluidity, φ. The value of either can be derived as a function of temperature or as a given value (i.e. for a dashpot).**

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

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

A Viscoelastic Material has the Following Properties:
• hysteresis is seen in the stress-strain
• stress relaxation occurs: step constant strain causes decreasing stress
• creep occurs: step constant stress causes increasing strain
• its stiffness depends on the strain rate or the stress rate.

Elastic versus viscoelastic behavior:

(a)   (b)
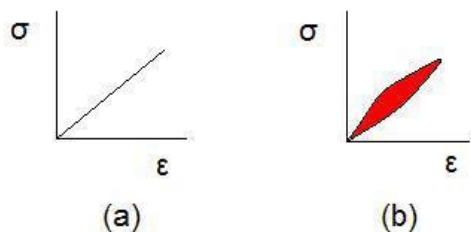
Stress-strain curves for a purely elastic material (a) and a viscoelastic material (b). The red area is a hysteresis loop and shows the amount of energy lost (as heat) in a loading and unloading cycle. It is equal to $\oint \sigma d\varepsilon$ where σ is stress and ε is strain. In other words, the hysteresis loop area represents the amount of energy during the loading and unloading process.

Unlike purely elastic substances, a viscoelastic substance has an elastic component and a viscous component. **The viscosity of a viscoelastic substance gives the substance a strain rate dependence on time.** Purely elastic materials do not dissipate energy (heat) when a load is applied, then removed. However, **a viscoelastic substance dissipates energy when a load is applied, then removed. Hysteresis is observed in the stress-strain curve, with the area of the loop being equal to the energy lost during the loading cycle.** Since viscosity is the resistance to thermally activated plastic deformation, a viscous material will lose energy through a loading cycle. **Plastic deformation results in lost energy, which is uncharacteristic of a purely elastic material's reaction to a loading cycle.**

Viscoplasticity
Viscoplasticity is a theory in continuum mechanics that describes the rate-dependent inelastic behavior of solids. Rate-dependence in this context means that the deformation of the material depends on the rate at which loads are applied. The inelastic behavior that is the subject of viscoplasticity is plastic deformation which means that the material undergoes unrecoverable deformations when a load level is reached. Rate-dependent plasticity is important for transient plasticity calculations. The main difference between rate-independent plastic and viscoplastic material models is that the latter exhibit not only permanent deformations after the application of loads but continue to undergo a creep flow as a function of time under the influence of the applied load.

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

Stress (σ)
*= strain (ε) change rate * viscosity factor (η)*
= dε/dt * η
The hysteresis loop area
= the integrated area of stress (σ) and strain (ε) curve
= $\oint \sigma d\varepsilon$

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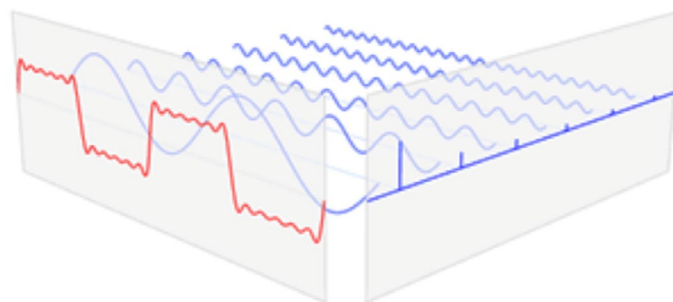
The Fourier transform converts the function's time-domain representation, shown in red, to the function's frequency-domain representation, shown in blue. The component frequencies, spread across the frequency spectrum, are represented as peaks in the frequency domain.

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 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 a 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: origin of term for details.

Results

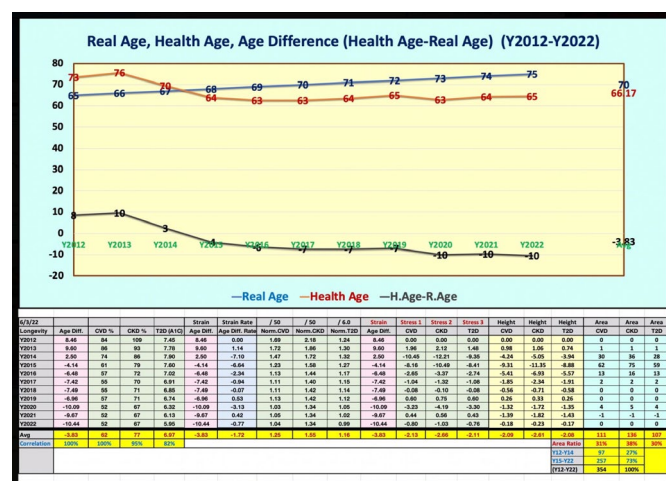Figure 1 shows the time-domain analysis results with data table.

Figure 1: Time-domain analysis results with data table

Figure 2 displays space-domain VGT stress-strain analysis results and frequency-domain FFT analysis of longevity versus CVD, CKD and T2D.
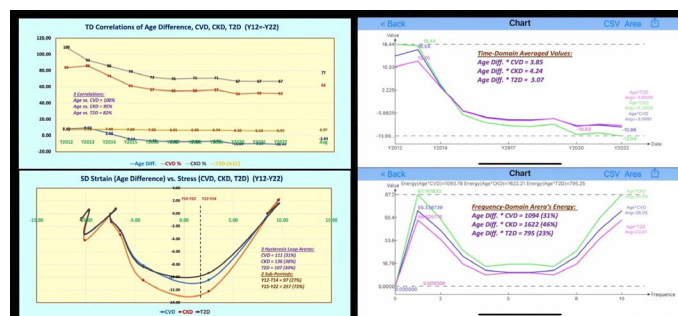

Figure 2: Space-domain VGT stress-strain analysis results and frequency-domain FFT analysis of longevity versus CVD, CKD, and T2D

Figure 3 depicts the comparison of results between two sub-periods of longevity versus CKD, CVD and T2D using both SD-VGT tool and FD-FFT tool.
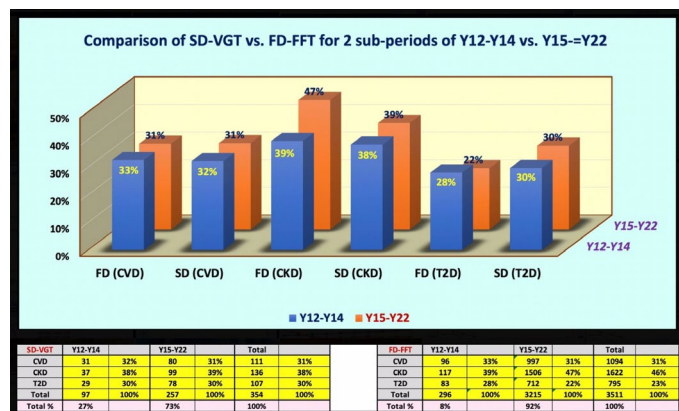

Figure 3: Comparison of results between two sub-periods of longevity versus CKD, CVD, and T2D using both SD-VGT tool and FD-FFT tool

SD-VGT	Y12-Y14		Y15-Y22		Total	
CVD	31	32%	80	31%	111	31%
CKD	37	38%	99	39%	136	38%
T2D	29	30%	78	30%	107	30%
Total	97	100%	257	100%	354	100%
Total %	27%		73%		100%	

FD-FFT	Y12-Y14		Y15-Y22		Total	
CVD	96	33%	997	31%	1094	31%
CKD	117	39%	1506	47%	1622	46%
T2D	83	28%	712	22%	795	23%
Total	296	100%	3215	100%	3511	100%
Total %	8%		92%		100%	

Conclusions

In summary, there are 5 observations from this energy analysis of longevity versus CVD risk, CKD risk, and T2D conditions using three different approaches, TD-R (R means correlation), SD-VGT, and FD-FFT.

(1)   *From the TD analysis of his collected data in 11 years, his **calculated correlations are longevity vs. CVD = 100%; longevity vs. CKD = 95%; longevity vs. T2D = 82%. These three correlations are ranked with the ranking order of heart attack/ stroke (100%), kidney failure (95%), and diabetic complications (82%). In other words, his longevity perspectives are dependent on complications associated with arteries in the heart or brain, micro-blood vessels in kidneys, and glucose levels in the blood system throughout the body.** This ranking order makes sense based on general biomedical knowledge and his personal medical history. Detailed results from the TD analysis further indicate that **the average variable values used in TD are 4.24 for (Age difference * CKD) and 3.85 for (Age difference * CVD); 3.07 for (Age difference * T2D) which has the same ranking order as the SD and FD results described below.***

(2) *Researching the part of stress-strain variation from the SD-VGT results, we can see that his Age differences decreased from 9.6 years in 2013 (a positive age difference means a shorter expected lifespan) to -10.44 years in 2022 (a negative age difference means a longer expected lifespan). His CVD risk % decreased from 86% in Y2013 to 52% in Y2021. His CKD risk % decreased from 109% in Y2012 to 67% in Y2022. His A1C values lessened from 7.45% in Y2012 to 5.95% in Y2022. **Generally speaking, his 3 biomarkers, CVD risk, CKD risk, and T2D (A1C) conditions, along with his Age difference numbers (health age minus real age) are decreasing year after year.***

(3)

 the 3 waveform patterns of stress-strain curves are highly similar to each other due to the usage of identical strain change rates, i.e. the Age difference change rate. When combined with 3 different viscosities, CVD, CKD, and T2D, these 3 stress magnitudes and 3 hysteresis loop areas are somewhat different but have similar waveform patterns. The conclusive observation is that **using the SD-VGT energy method, CKD generates the highest energy level of 136 (38%), CVD produces the middle energy level of 111 (31%), and T2D creates the lowest energy level of 107 (30%). Another important SD-VGT observation is that the sub-period's energy ratios of 97 (27%) for the first 3 years of Y2012-Y2014 versus 257 (73%) for the next 8 years of Y2015-Y2022.**

(4) ***Using the FD-FFT energy analysis, the results are 1622 (46%) for the case of (Age difference * CKD); 1094 (31%) for the case of (Age difference * CVD); and 795 (23%) for the case of (Age difference * T2D). The ranking order of FD-FFT results is similar to the ranking order of SD-VGT results.***

(5) Regarding the sub-period energy analysis results, ***for the sub-period of Y12-Y14, the SD-VGT results*** are CKD=38%, CVD=32%, and T2D=30%. The FD-FFT results are CKD=39%, CVD=33%, and T2D=28% which are almost identical. For the sub-period energy analysis results, ***the Y15-Y22 SD-VGT results are CKD=39%, CVD=31%, and T2D=30%. The FD-FFT results*** are CKD=47%, CVD=31%, and T2D=22% which ***are quite similar to each other except that CKD is bigger and T2D is smaller.*** Generally speaking, the 2 different energy methods (SD-VGT vs. FD-FFT) for longevity have yielded similar output patterns of energy ratio between 2 sub-periods. ***The bar chart in Figure 3 also shows graphically that the relative heights of the bars are comparable to each other between SD-VGT method and FD-FFT method.***

Both the SD-VGT energy tool adopted from engineering and the FD-FFT energy tool adopted from physics have yielded extremely similar results with interesting clues. They provide useful interpretation of biomedical results from this research work on longevity perspectives from CVD Risk, CKD risk, and T2D conditions. Although the author cannot precisely predict the future outlook of his lifespan, by using a scientific way (mathematics and physics) to project his longevity perspectives can provide useful guidance to achieve his ultimate goal of extended healthy life.

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.

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