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# Viscoelastic or Viscoplastic Glucose Theory (VGT #88): An Investigation on the Influences of Body Weight on 3 Diseases, Cardiovascular Disease, Chronic Kidney Disease, and Type 2 Diabetes Using Data Collected from Y2012 to Y2022 from a Type 2 Diabetes Patient Based on GH-Method: Math-Physical Medicine, Especially the VGT Tool (No. 678)

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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 676 research papers in various journals using different math-physical medicine methodologies (MPM). Beginning with paper No. 578 dated 1/8/2022, he has written a total of 83 medical research and 4 economic research papers using viscoelasticity and viscoplasticity theories (VGT) tools from physics and engineering disciplines. These 87 papers aim to explore some hidden physical behaviors and provide a deeper quantitative understanding of the inter-relationships of a selected output (or symptom) versus singular input or multiple inputs (or root causes, risk factors, 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 severe 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 using three key US economic measurements. From this economic exercise, he realized that the established theory of viscoelasticity and viscoplasticity (from the physics branch of science) should not only be limited to a smaller 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 are 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 the full-text article. In this article, the first step is to collect the output data (strain or ε) on a time scale, e.g. cardiovascular disease (CVD) risk, chronic kidney disease (CKD) risk, or type 2 diabetes (T2D). The second step is to calculate the output change rate with time (dε/dt), e.g. the change rate of CVD, CKD, and T2D over each year. The third step is to collect the input data (viscosity or η) on a time scale, e.g. annual average body weight (BW). 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-symptom) curve in a space domain (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

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input and output dataset. These energy values can also be considered as the degrees of influence on output by inputs. After providing this description, he would like to use the following re-defined general VGT equation to address the unique "time-dependency characteristics" of engineering, economics, and medical variables. He can then establish a set of generalized stress-strain equations which can be displayed in a two-dimensional space domain (SD) as follows: 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 by the average viscosity number 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. In this article, he decides to normalize his A1C values by a factor of 16.67 (=100/6). He selects A1C of 6.0 as the standard of healthy A1C condition for a long-term T2D patient like himself and then multiplies it with 100 to make them more comparable with both CVD risk % and CKD risk %. Using un-normalized values will 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 original variables into a set of "dimensionless variables" for easier numerical comparison and result interpretation. This particular paper No. 678 is somewhat different from his previous VGT papers which have focused on single output versus either single input or multiple inputs. This particular paper covers results from 3 separate cases of different outputs, i.e. CVD, CKD, and T2D, versus a single common input of body weight (BW). In addition, using a time-domain (TD) analysis, he has conducted straightforward statistical correlation coefficient calculations between BW (input) versus 3 different outputs, i.e. CVD, CKD, and T2D. In summary, there are 3 observations from this VGT analysis of 3 outputs, CVD Risk %, CKD Risk %, and T2D conditions versus a single common input of BW: (1) From the TD analysis of his collected data in 11 years (Figure 1), the calculated correlations are: CVD vs. BW = 94%; CKD vs. BW = 98%; T2D vs. BW = 74%. It is obvious that these statistical correlation analysis results have shown that, with a sufficiently large time window of 11-year data, three high positive correlations are observed with CVD risk %, CKD risk %, and T2D versus BW. Nevertheless, the following specific biomedical observation holds true that his obesity (BW) contributes to or at least strongly influences all 3 diseases, CVD, CKD, and T2D. However, in the author's case, the highest connectivity of 98% with CKD reflects the fact that in 2010-2012, his diabetes doctor recommended him to have kidney dialysis. He has already suffered 5 CVD episodes before 2010 revealing the second-highest connectivity with CVD of 94%. From this statistical correlation analysis results, it is evident that BW is a strong factor in developing CVD, CKD, and T2D. (2) Researching the part of strain variation from the VGT results (Figures 2 and 3), we can see that his CVD risk % decreased from 86% in Y2013 to 52% in Y2021. His CKD risk % reduced from 109% in Y2012 (he already had CKD in 2010-2012) to 67% in Y2022. His A1C values lessened from 7.45% in Y2012 to 5.95% in Y2022. His body weight started at 189 lbs. (BMI 27.91 overweight) in Y2012 and decreased to 169 lbs. (BMI 24.95 normal weight) in Y2021. Generally speaking, all of his 3 biomarkers, CVD risk, CKD risk %, T2D (A1C) conditions, and his body weight (BW) are decreasing year after year. It should be pointed out that the 3 different strain (CVD) change rates have created 3 different looks of waveform patterns of these 3 stress-strain curves resulting from the same BW input. (3) Researching the stress-strain diagrams from the VGT analysis results (Figures 2 and 3), these 3 waveform patterns of stress-strain curves are different from each other due to their strain change rates varying among CVD, CKD, and T2D, respectively. When combining the same viscosity, i.e. body weight (BW), the final 3 detailed waveform magnitudes and 3 hysteresis loop areas become different from each other. The combination of strain and stress components have created three actual sizes of the hysteresis loop areas or its associated energy levels, i.e. the degrees of influence of the stresses on the strain. The conclusive observation from this stress-strain diagram is that BW has generated the largest energy of 341 with CKD, the middle-level energy of 280 with CVD, and the smallest energy of 175 with T2D. Another important observation is that the sub-periods energy ratios for the first 5 year of Y2012-Y2016 versus the second 6 years of Y2017-Y2022 are: CVD = 96% : 4%; CKD = 95% : 5%; T2D = 59% : 41%. For both CVD and CKD, the first sub-period of Y2012-2016 is the most dangerous period for the author. However, regarding T2D, they are more or less evenly distributed between the 2 sub-periods. This indicates that diabetes is a more troublesome condition to be dealt with because it is almost impossible to "repair" and very difficult to "control" as well. However, the good news is that once his T2D condition is improved by ~2% of HbA1C reduction, his CVD and CKD risks are significantly reduced (by almost 40% of reduction) and his life-threatening risks of heart attacks, strokes, and kidney failures are then removed. This VGT energy tool adopted from engineering and physics can indeed provide some interesting clues for useful interpretation of results from this research work on CVD Risk, CKD Risk, and T2D Conditions versus a common input of body weight (BW). This article has quantitatively proven his

correct strategy of dealing with his health threats over the past 13 years. At first, he focused on his weight control via strict food portion control, and, in parallel, he also concentrated on his glucose control via carbs/sugar reduction along with post-meal walking exercise. By being persistent and patient in following this lifestyle management process, he has reduced the risks of developing CVD/stroke and CKD.

**Keywords:** Viscoelastic; Viscoplastic; Cardiovascular disease; Chronic kidney disease; Body weight; Postprandial plasma glucose; Fasting plasma glucose; Type 2 diabetes; COVID-19

**Abbreviations:** CVD: cardiovascular disease; CKD: chronic kidney disease; T2D: type 2 diabetes; PPG: postprandial plasma glucose; FPG: fasting plasma glucose; SD: space domain; TD: time domain; MPM: math-physical medicine

## 1. INTRODUCTION

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 676 research papers in various journals using different math-physical medicine methodologies (MPM).

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Papers No. 671 through No. 674 focused on the COVID infectious disease using three key US economic measurements. From this economic exercise, he realized that the established theory of viscoelasticity and viscoplasticity (from the physics branch of science) should not only be limited to a smaller 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 are 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 the full-text article.

In this article, the first step is to collect the output data (strain or ε) on a time scale, e.g. cardiovascular disease (CVD) risk, chronic kidney disease (CKD) risk, or type 2 diabetes (T2D). The second step is to calculate the output change rate with time (dε/dt), e.g. the change rate of CVD, CKD, and T2D over each year. The third step is to collect the input data (viscosity or η) on a time scale, e.g. annual average body weight (BW). 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-symptom) curve in a space domain (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 description, he would like to use the following re-defined general VGT equation to address the unique “time-dependency characteristics” of engineering, economics, and medical variables. He can then establish a set of generalized stress-strain equations which can be displayed in a two-dimensional space domain (SD) as follows:

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 by the average viscosity number 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. In this article, he decides to normalize his A1C values by a factor of 16.67 (=100/6). He selects A1C of 6.0 as the standard of healthy A1C condition for a long-term T2D patient like himself and then multiplies it with 100 to make them more comparable with both CVD risk % and CKD risk %. Using un-normalized values will 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 original variables into a set of "dimensionless variables" for easier numerical comparison and result interpretation.

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In addition, using a time-domain (TD) analysis, he has conducted straightforward statistical correlation coefficient calculations between BW (input) versus 3 different outputs, i.e. CVD, CKD, and T2D.

## 2. METHODS

### 2.1 The author's case of diabetes

The author has been a severe T2D patient since 1996. He weighed 220 lb. (100 kg, BMI 32.5) at that time. By 2010, he still weighed 198 lb. (BMI 29.2) with average daily glucose of 250 mg/dL (HbA1C of 10%). During that year, his triglycerides reached 1161 and albumin-creatinine ratio (ACR) at 116. He also suffered from five cardiac episodes within a decade. In 2010, three independent physicians warned him regarding his need for kidney dialysis treatment and his future high risk of dying from his severe diabetic complications. Other than the cerebrovascular disease (stroke), he has suffered most of the known diabetic complications, including both macro-vascular and micro-vascular complications.

In 2010, he decided to launch his self-study on endocrinology, diabetes, and food nutrition to save his own life. During 2015 and 2016, he developed four prediction models related to diabetes conditions: weight, PPG, fasting plasma glucose (FPG), and A1C. As a result, from using his developed mathematical metabolism index (MI) model in 2014 and the four prediction tools, by end of 2016, his weight was reduced from 220 lbs. (100 kg, BMI 32.5) to 176 lbs. (89 kg, BMI 26.0), waistline from 44 inches (112 cm) to 33 inches (84 cm), average finger glucose reading from 250 mg/dL to 120 mg/dL, and lab-tested A1C from 10% to ~6.5%. One of his major accomplishments is that he no longer takes any diabetes medications as of 12/8/2015.

In 2017, he has achieved excellent results on all fronts, especially glucose control. However, during the pre-COVID period of 2018 and 2019, he traveled to approximately 50+ international cities to attend 65+ medical conferences and made ~120 oral presentations. This hectic schedule inflicted damage to his diabetes control, through dining out frequently, post-meal exercise disruption, jet lag, and along with the overall metabolic impact due to his irregular life patterns through a busy travel schedule; therefore, his glucose control and overall metabolism state were somewhat affected during this two-year heavier traveling period.

Since 2020, living in a COVID-19 quarantined lifestyle, not only has he published 400+ medical papers in 100+ journals, but he has also reached his best health conditions in the past 26 years. By the beginning of 2022, his weight was further reduced to 168 lbs. (BMI 24.8) along with a 5.8% A1C value (beginning level of prediabetes), without having any medication interventions or insulin injections. These good results are due to his non-traveling, low-stress, and regular daily life routines. Of course, his knowledge of chronic diseases, practical lifestyle management experiences, and development of various high-tech tools contribute to his excellent health status since 1/19/2020, the beginning date of his self-quarantined life.

On 5/5/2018, he applied a continuous glucose monitoring (CGM) sensor device on his upper arm and checks his glucose measurements every 5 minutes for a total of ~288 times each day. He has maintained the same measurement pattern to the present day. In his research work, he uses his CGM sensor glucose at a time interval of 15 minutes (96 data per day). Incidentally, the difference in average sensor glucoses between 5-minute intervals and 15-minute intervals is only 0.7% (average glucose of 112.15 mg/dL for 5-minutes and average glucose of 111.33 mg/dL for 15-minutes with a correlation of 96% between these two sensor glucose curves) during the period from 2/19/20- to 5/9/22.

Therefore, over the past 12 years, he could study and analyze the collected ~3 million data regarding his health status, medical conditions, and lifestyle details. He applies his knowledge, models, and tools from mathematics, physics, engineering, and computer science to conduct his medical research work. His research is based on the aims of achieving both “high precision” with “quantitative proof” in the medical findings.

The following timetable provides a rough sketch of the emphasis in his medical research during each stage:

2000-2013: Self-study diabetes and food nutrition, developing a data collection and analysis software.

2014: Develop a mathematical model of metabolism, using engineering modeling and advanced mathematics.

2015: Weight & FPG prediction models, using neuroscience.

2016: PPG & HbA1C prediction models, using optical physics, artificial intelligence (AI), and neuroscience.

2017: Complications due to macro-vascular research, such as Cardiovascular disease (CVD), coronary heart diseases (CHD), and stroke, using pattern analysis and segmentation analysis.

2018: Complications due to micro-vascular research such as kidney (CKD), bladder, foot, and eye issues (DR).

2019: CGM big data analysis, using wave theory, energy theory, frequency domain analysis, quantum mechanics, and AI.

2020: Cancer, dementia, longevity, geriatrics, DR, hypothyroidism, diabetic foot, diabetic fungal infection, and linkage between metabolism and immunity, learning about certain infectious diseases, such as COVID-19.
2021: Applications of linear elastic glucose theory (LEGT) and perturbation theory from quantum mechanics on medical research subjects, such as chronic diseases and their complications, cancer, and dementia.

2022: Applications of viscoelastic/viscoplastic glucose theory (LEGT) on 81 biomedical research cases.

Again, to date, he has spent around 40,000 hours self-studying and researching medicine. He has collected and calculated more than three million pieces of data regarding his medical conditions and lifestyle details. In addition, he has written 676 medical research notes and published ~600 papers in 100+ various medical and engineering journals. Moreover, he has also given ~120 presentations at ~65 international medical conferences. He has continuously dedicated his time (11-12 hours per day and work each day of a year, without rest) and efforts to his medical research work and shared his findings and learnings with other patients worldwide.

## 2.2 MPM background

To learn more about his developed GH-Method: math-physical medicine or MPM methodology, readers can select the following three articles from the 400+ published medical papers.

The first paper, No. 386, describes his MPM methodology in a general conceptual format. The second paper, No. 387, outlines the history of his personalized diabetes research, various application tools, and the differences between the biochemical medicine (BCM) approach versus the MPM approach. The third paper, No. 397, depicts a general flow diagram containing ~10 key MPM research methods and different tools.

All of the listed papers in the Reference section are his written and published medical research papers.

### 2.3 Elasticity, plasticity, viscoelasticity, and viscoplasticity (LEGT & VGT)

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

What are elastic materials?

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

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

What are viscous materials?

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

What is viscoelastic?

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

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

Elastic behavior versus viscoelastic behavior

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

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

The following brief introductions are excerpts from Wikipedia:

“Elasticity (physics):

The physical property is when materials or objects return to their original shape after deformation.

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

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

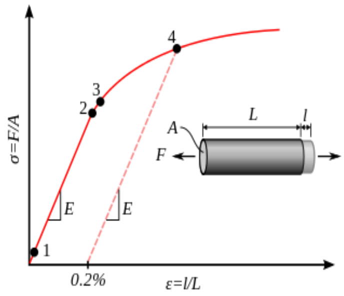
In engineering, the elasticity of a material is quantified by the elastic modulus such as the Young's modulus, bulk modulus or shear modulus which measure the amount of stress needed to achieve a unit of strain; a higher modulus indicates that the material is harder to deform. The material's elastic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

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

Plasticity (physics):

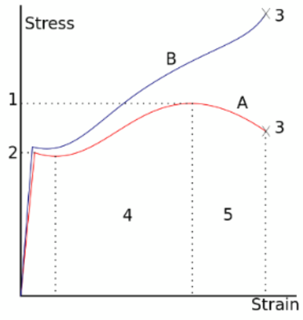
Deformation of a solid material undergoing non-reversible changes of shape in response to applied forces.

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



A stress-strain curve showing typical yield behavior for nonferrous alloys.

1. True elastic limit
2. Proportionality limit
3. Elastic limit
4. Offset yield strength



A stress-strain is typical of structural steel.

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

For many ductile metals, tensile loading applied to a sample will cause it to behave in an elastic manner. Each increment of load is accompanied by a proportional increment in extension. When the load is removed, the piece returns to its original size. However, once the load exceeds a threshold – the yield strength – the extension increases more rapidly than in the elastic region; now when the load is removed, some degree of extension will remain.

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

Viscoelasticity:

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

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

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

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

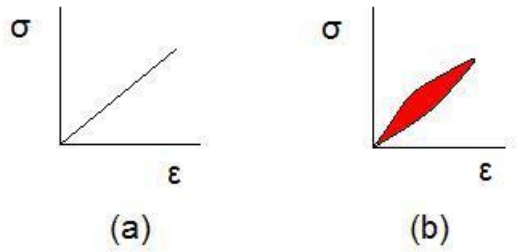
Depending on the change of strain rate versus stress inside a material, the viscosity can be categorized as having a linear, non-linear, or plastic response. In addition, when the stress is independent of this strain rate, the material exhibits plastic deformation. Many viscoelastic materials exhibit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

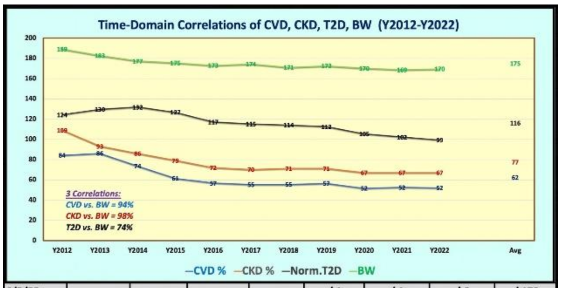
**Note:** For a more detailed description, please refer to the "consolidated method" section which is given at the beginning of the special issue.

## 3. RESULTS

Figure 1 shows the time-domain analysis results of CVD risk, CKD risk, and T2D versus BW, with multiple correlations over 11 years.

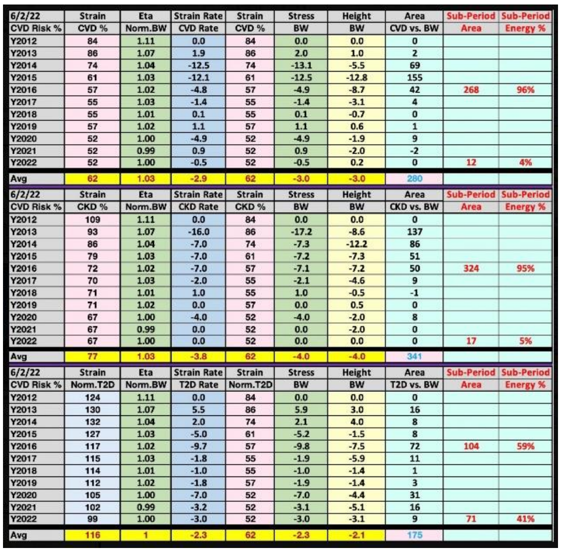
Figure 2 displays the data table of 3 VGT analyses.

Figure 3 depicts the space-domain VGT stress-strain analysis results of CVD risk, CKD risk, and T2D versus BW over 11 years.



| 6/2/22 | | | | | / 1 | / 1 | / 6 | / 170 |
|---|---|---|---|---|---|---|---|---|
| CVD Risk % | CVD % | CKD % | T2D (A1C) | BW | Norm.CVD | Norm.CKD | Norm.T2D | Norm.BW |
| Y2012 | 84 | 109 | 7.45 | 189 | 84 | 109 | 124 | 1.11 |
| Y2013 | 86 | 93 | 7.78 | 183 | 86 | 93 | 130 | 1.07 |
| Y2014 | 74 | 86 | 7.90 | 177 | 74 | 86 | 132 | 1.04 |
| Y2015 | 61 | 79 | 7.60 | 175 | 61 | 79 | 127 | 1.03 |
| Y2016 | 57 | 72 | 7.02 | 173 | 57 | 72 | 117 | 1.02 |
| Y2017 | 55 | 70 | 6.91 | 174 | 55 | 70 | 115 | 1.03 |
| Y2018 | 55 | 71 | 6.85 | 171 | 55 | 71 | 114 | 1.01 |
| Y2019 | 57 | 71 | 6.74 | 173 | 57 | 71 | 112 | 1.02 |
| Y2020 | 52 | 67 | 6.32 | 170 | 52 | 67 | 105 | 1.00 |
| Y2021 | 52 | 67 | 6.13 | 169 | 52 | 67 | 102 | 0.99 |
| Y2022 | 52 | 67 | 5.95 | 170 | 52 | 67 | 99 | 1.00 |
| Avg | 62 | 77 | 6.97 | 175 | 62 | 77 | 116 | 1.03 |
| R | 100% | 95% | 80% | 94% | | | | |
| R | 95% | 100% | 73% | 98% | | | | |
| R | 80% | 73% | 100% | 74% | | | | |
| R | 94% | 98% | 74% | 100% | | | | |

**Figure 1:** Time-domain analysis results of CVD risk, CKD risk, and T2D versus BW with multiple correlations for 11 years.



| 6/2/22 | Strain | Eta | Strain Rate | Strain | Stress | Height | Area | Sub-Period | Sub-Period |
|---|---|---|---|---|---|---|---|---|---|
| CVD Risk % | CVD % | Norm.BW | CVD Rate | CVD % | BW | BW | CVD vs. BW | Area | Energy % |
| Y2012 | 84 | 1.11 | 0.0 | 84 | 0.0 | 0.0 | 0 | | |
| Y2013 | 86 | 1.07 | 1.9 | 86 | 2.0 | 1.0 | 2 | | |
| Y2014 | 74 | 1.04 | -12.5 | 74 | -13.1 | -5.5 | 69 | | |
| Y2015 | 61 | 1.03 | -12.1 | 61 | -12.5 | -12.8 | 155 | | |
| Y2016 | 57 | 1.02 | -4.8 | 57 | -4.9 | -8.7 | 42 | 268 | 96% |
| Y2017 | 55 | 1.03 | -1.4 | 55 | -1.4 | -3.1 | 4 | | |
| Y2018 | 55 | 1.01 | 0.1 | 55 | 0.1 | -0.7 | 0 | | |
| Y2019 | 57 | 1.02 | 1.1 | 57 | 1.1 | 0.6 | 1 | | |
| Y2020 | 52 | 1.00 | -4.9 | 52 | -4.9 | -1.9 | 9 | | |
| Y2021 | 52 | 0.99 | 0.9 | 52 | 0.9 | -2.0 | -2 | | |
| Y2022 | 52 | 1.00 | -0.5 | 52 | -0.5 | 0.2 | 0 | 12 | 4% |
| Avg | 62 | 1.03 | -2.9 | 62 | -3.0 | -3.0 | 280 | | |

| 6/2/22 | Strain | Eta | Strain Rate | Strain | Stress | Height | Area | Sub-Period | Sub-Period |
|---|---|---|---|---|---|---|---|---|---|
| CVD Risk % | CKD % | Norm.BW | CKD Rate | CKD % | BW | BW | CKD vs. BW | Area | Energy % |
| Y2012 | 109 | 1.11 | 0.0 | 84 | 0.0 | 0.0 | 0 | | |
| Y2013 | 93 | 1.07 | -16.0 | 86 | -17.2 | -8.6 | 137 | | |
| Y2014 | 86 | 1.04 | -7.0 | 74 | -7.3 | -12.2 | 86 | | |
| Y2015 | 79 | 1.03 | -7.0 | 61 | -7.2 | -7.3 | 51 | | |
| Y2016 | 72 | 1.02 | -7.0 | 57 | -7.1 | -7.2 | 50 | 324 | 95% |
| Y2017 | 70 | 1.03 | -2.0 | 55 | -2.1 | -4.6 | 9 | | |
| Y2018 | 71 | 1.01 | 1.0 | 55 | 1.0 | -0.5 | -1 | | |
| Y2019 | 71 | 1.02 | 0.0 | 57 | 0.0 | 0.5 | 0 | | |
| Y2020 | 67 | 1.00 | -4.0 | 52 | -4.0 | -2.0 | 8 | | |
| Y2021 | 67 | 0.99 | 0.0 | 52 | 0.0 | -2.0 | 0 | | |
| Y2022 | 67 | 1.00 | 0.0 | 52 | 0.0 | 0.0 | 0 | 17 | 5% |
| Avg | 77 | 1.03 | -3.8 | 62 | -4.0 | -4.0 | 341 | | |

| 6/2/22 | Strain | Eta | Strain Rate | Strain | Stress | Height | Area | Sub-Period | Sub-Period |
|---|---|---|---|---|---|---|---|---|---|
| CVD Risk % | Norm.T2D | Norm.BW | T2D Rate | Norm.T2D | BW | BW | T2D vs. BW | Area | Energy % |
| Y2012 | 124 | 1.11 | 0.0 | 84 | 0.0 | 0.0 | 0 | | |
| Y2013 | 130 | 1.07 | 5.5 | 86 | 5.9 | 3.0 | 16 | | |
| Y2014 | 132 | 1.04 | 2.0 | 74 | 2.1 | 4.0 | 8 | | |
| Y2015 | 127 | 1.03 | -5.0 | 61 | -5.2 | -1.5 | 8 | | |
| Y2016 | 117 | 1.02 | -9.7 | 57 | -9.8 | -7.5 | 72 | 104 | 59% |
| Y2017 | 115 | 1.03 | -1.8 | 55 | -1.9 | -5.9 | 11 | | |
| Y2018 | 114 | 1.01 | -1.0 | 55 | -1.0 | -1.4 | 1 | | |
| Y2019 | 112 | 1.02 | -1.8 | 57 | -1.9 | -1.4 | 3 | | |
| Y2020 | 105 | 1.00 | -7.0 | 52 | -7.0 | -4.4 | 31 | | |
| Y2021 | 102 | 0.99 | -3.2 | 52 | -3.1 | -5.1 | 16 | | |
| Y2022 | 99 | 1.00 | -3.0 | 52 | -3.0 | -3.1 | 9 | 71 | 41% |
| Avg | 116 | 1 | -2.3 | 62 | -2.3 | -2.1 | 175 | | |

**Figure 2:** Data table of 3 VGT analyses.

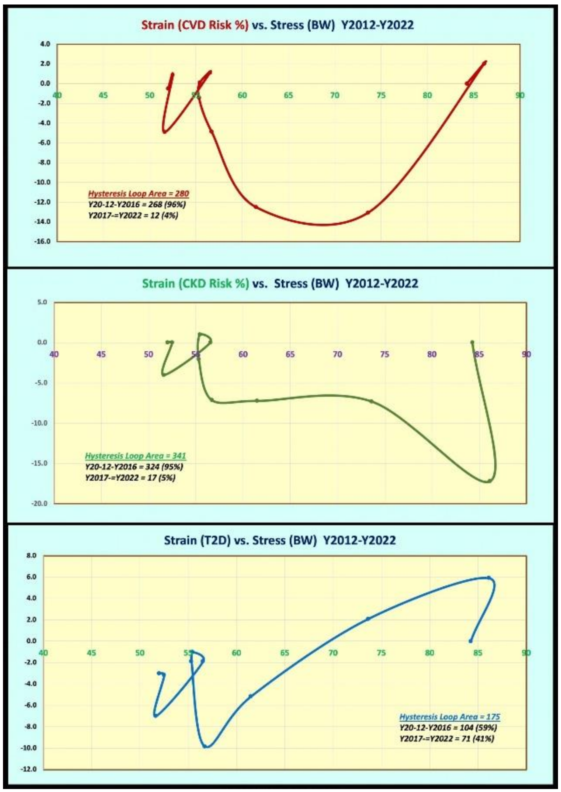


**Figure 3:** Space-domain VGT stress-strain analysis results of CVD risk, CKD risk, and T2D versus BW for 11 years.

## 4. CONCLUSION

In summary, there are 3 observations from this VGT analysis of 3 outputs, CVD Risk %, CKD Risk %, and T2D conditions versus a single common input of BW:

(1) From the TD analysis of his collected data in 11 years (Figure 1), the calculated correlations are: CVD vs. BW = 94%; CKD vs. BW = 98%; T2D vs. BW = 74%. It is obvious that these statistical correlation analysis

results have shown that, with a sufficiently large time window of 11-year data, three high positive correlations are observed with CVD risk %, CKD risk %, and T2D versus BW. Nevertheless, the following specific biomedical observation holds true that his obesity (BW) contributes to or at least strongly influences all 3 diseases, CVD, CKD, and T2D. However, in the author's case, the highest connectivity of 98% with CKD reflects the fact that in 2010-2012, his diabetes doctor recommended him to have kidney dialysis. He has already suffered 5 CVD episodes before 2010 revealing the second-highest connectivity with CVD of 94%. From this statistical correlation analysis results, it is evident that BW is a strong factor in developing CVD, CKD, and T2D.

(2) Researching the part of strain variation from the VGT results (Figures 2 and 3), we can see that his CVD risk % decreased from 86% in Y2013 to 52% in Y2021. His CKD risk % reduced from 109% in Y2012 (he already had CKD in 2010-2012) to 67% in Y2022. His A1C values lessened from 7.45% in Y2012 to 5.95% in Y2022. His body weight started at 189 lbs. (BMI 27.91 overweight) in Y2012 and decreased to 169 lbs. (BMI 24.95 normal weight) in Y2021. Generally speaking, all of his 3 biomarkers, CVD risk, CKD risk %, T2D (A1C) conditions, and his body weight (BW) are decreasing year after year. It should be pointed out that the 3 different strain (CVD) change rates have created 3 different looks of waveform patterns of these 3 stress-strain curves resulting from the same BW input.

(3) Researching the stress-strain diagrams from the VGT analysis results (Figures 2 and 3), these 3 waveform patterns of stress-strain curves are different from each other due to their strain change rates varying among CVD, CKD, and T2D, respectively. When combining the same viscosity, i.e. body weight (BW), the final 3 detailed waveform magnitudes and 3 hysteresis loop areas become different from each other. The combination of strain and stress components have created three actual sizes of the hysteresis loop areas or its associated energy levels, i.e. the degrees of influence of the stresses on the strain. The conclusive observation from this stress-strain diagram is that BW has generated the largest energy of 341 with CKD, the middle-level energy of 280 with CVD, and the smallest energy of 175 with T2D. Another important observation is that the sub-periods energy ratios for the first 5 year of Y2012-Y2016 versus the second 6 years of Y2017-Y2022 are: CVD = 96% : 4%; CKD = 95% : 5%; T2D = 59% : 41%. For both CVD and CKD, the first sub-period of Y2012-2016 is the most dangerous period for the author. However, regarding T2D, they are more or less evenly distributed between the 2 sub-periods. This indicates that diabetes is a more troublesome condition to be dealt with because it is almost impossible to "repair" and very difficult to "control" as well. However, the good news is that once his T2D condition is improved by ~2% of HbA1C reduction, his CVD and CKD risks are significantly reduced (by almost 40% of reduction) and his life-threatening risks of heart attacks, strokes, and kidney failures are then removed.

This VGT energy tool adopted from engineering and physics can indeed provide some interesting clues for useful interpretation of results from this research work on CVD Risk, CKD Risk, and T2D Conditions versus a common input of body weight (BW). This article has quantitatively proven his correct strategy of dealing with his health threats over the past 13 years. At first, he focused on his weight control via strict food portion control, and, in parallel, he also concentrated on his glucose control via carbs/sugar reduction along with post-meal walking exercise. By being persistent and patient in following this lifestyle management process, he has reduced the risks of developing CVD/stroke and CKD.

## 5. REFERENCES

For editing purposes, the majority of the references in this paper, which are self-references, have been removed. Only references from other authors' published sources remain. The bibliography of the author's original self-references can be viewed at www.eclairemd.com.

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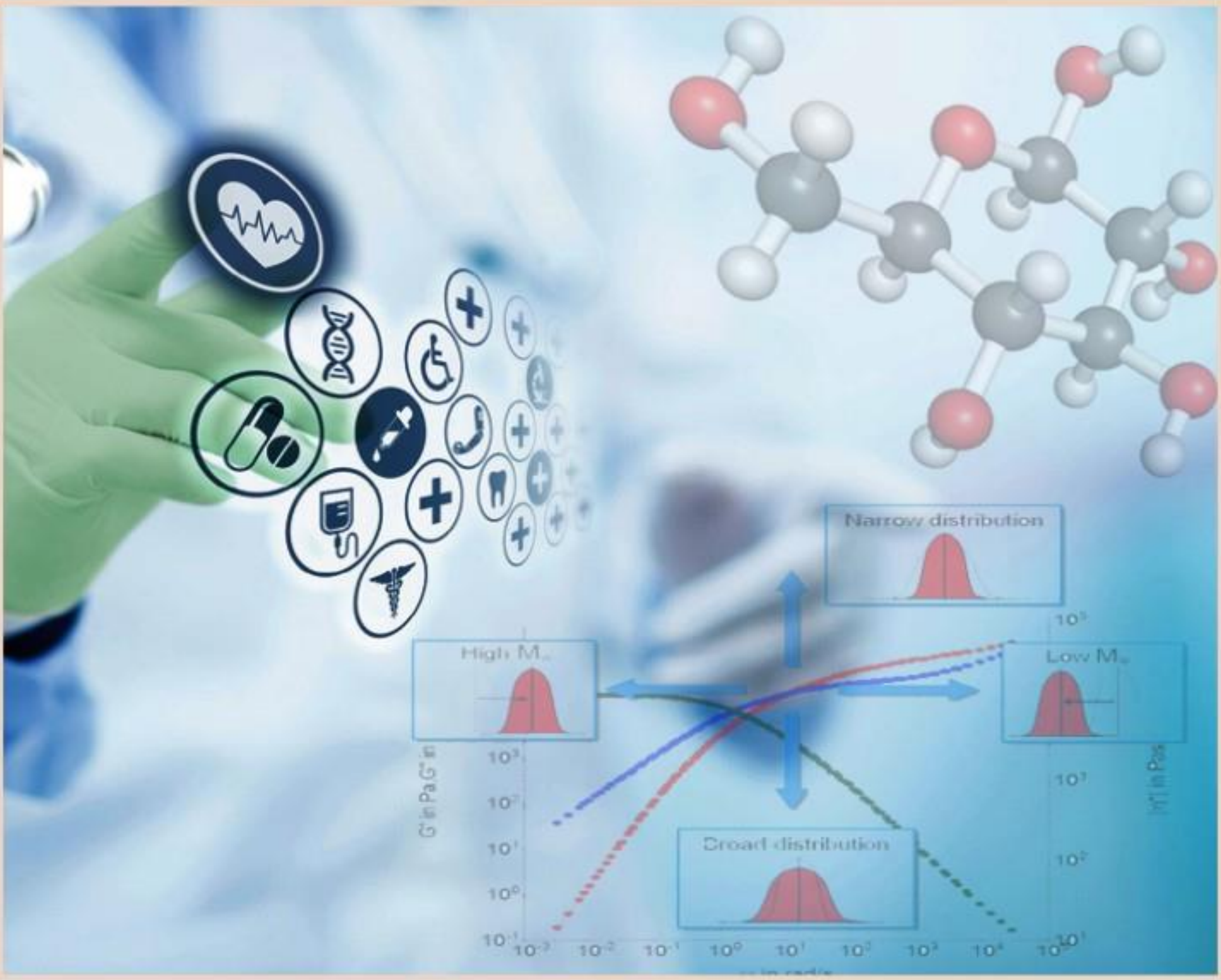
The GH-Method

# Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

Gerald C. Hsu



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