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The GH-Method

Viscoelastic and Viscoplastic Glucose Theory (VGT #34): Applying VEGT and Viscoelastic Perturbation Model and Using Carbs/Sugar Intake Amount Along with Post-Meal Walking K-Steps as Two Constant Viscosity Factors to Predict Two LEGT PPG Values from 8/8/2018 to 2/26/2022 Based on GH-Method: Math-Physical Medicine (No. 615)

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Note: Readers who want to get a quick overview can read the abstract, results, and graphs.

Abstract

The author has studied strength of materials and theory of elasticity through his undergraduate courses at the University of Iowa (UI). He also conducted research work and earned a master's degree in Biomechanics under Professor James Andrews. In 1970-1971, he used a combined spring and dashpot model to simulate the behaviors of human joints, bones, muscles, and tendons, where he took some related courses at the UI School of Medicine, to investigate the soldier-weapon biophysical interactions during the Vietnam war era. Next, 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 structure elements. To further his education, he took additional graduate courses in various fields of fluid dynamics, thermodynamics, bridge design using energy absorption pad, and soil mechanics under earthquake forces which deal with "time-dependent issues". Since then, many advancements have been made in the biomechanics branch, especially with human body live tissues that possess certain viscoelastic characteristics, such as bones, muscles, cartilages, tendons (connect bone to muscle), ligaments (connect bone to bone), fascia, and skin. For example, the author suffered plantar fasciitis for many years. He understood that calf stretching exercises or wearing the night splint dorsiflexes forefoot, at the back of the foot, increases plantar fascia tension to offer stress-relief from the pain. This model where muscles and tendons connect the lower leg and foot is a form of viscoelastic study for medical problem solving. When dealing with human internal organs, it is not easy to conduct live experiments to obtain accurate measurements for the biomedical material properties. Blood itself is a viscous material (time-dependent) and its viscosity factor may fall between water, honey, syrup, or gel. However, the author's research focus is on "glucose" where the blood sugar amount is produced by the liver and carried by red blood cells, not the blood itself. It is nearly impossible to measure the material geometry or material properties to determine the viscosity of glucose, like in engineering research work. Although postprandial plasma glucose (PPG) is strongly influenced by both energy input via carbs/sugar intake amount (~60%) and energy output via post-meal exercise level (~40%). Fundamentally, the PPG level is also dependent upon the individual's health conditions in regard to liver cells and pancreatic beta cells, which produce glucose and release insulin to control the glucose level in blood. Therefore, the author selects a combined value of (carbs/sugar grams and post-meal walking k-steps with respective weighting factors of GH-Modulus as the viscosity factor (η). Based on this knowledge, he applies the "concept" of viscoelasticity and viscoplasticity" to construct an analogy model of time-dependent glucose behaviors. The author's background includes mathematics, physics, and various engineering disciplines, not including biology and chemistry. He can only investigate the observed biophysical phenomena in the medical field using his ready-learned math-physical tools. For example, he studied both modern physics and quantum mechanics during his school days; therefore, he applied the theory of relativity on interactions among the organs in the human body (an inner space) which is similar to the inter-relationships among the planets in the universe (an outer space). He applied this analogy of using the theory of relativity in his medical research over the past few years to identify and prove the inter-connectivity of internal organs. By utilizing the perturbation theory from quantum mechanics, he

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was able to obtain an approximate but accurate predicted glucose level along with the estimation for the associated energy of glucose. In addition, he conducted some investigations on glucose behaviors using elasticity theory and plasticity theory (both static and dynamic), which allowed him to write a few articles on his research findings. In his previous research work using linear elastic glucose theory (LEGT), he has developed two GH-Moduli, GH.p and GH.w as two modification factors or "weighting factors" for food and exercise, as two major influences on PPG values. Recently, the author has received an email from Professor Norman Jones, his academic advisor at MIT. Professor Jones wrote that: "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 emphasized the time-dependence of various behaviours in the body. Just a thought." His suggestion has triggered the author's strong interest and desire to research this subject on glucose or other biomarker behaviors further by using the viscosity theory. Nevertheless, the medical field is still quite different from the engineering field, where the engineering materials such as steel, copper, concrete, and aluminum are inorganic 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 cells are organic and go through many distinct stages over their natural lifespans, such as birth, splitting, growth, development, mutation, repair, sickness, and death. Therefore, the biomedical properties are "moving targets" which vary with the individual person, severity of diseases, and selected different time-windows. In other words, they are both time-dependent and specimen-dependent. Furthermore, some basic engineering material characteristics, such as calculations for the cross-section of a subject, bending moment of resistance, or the shape factors in solid mechanics, etc. are not applicable in this biomedical glucose analogy study of elasticity/plasticity or viscoelasticity/viscoplasticity. In the author's opinion, the most important part is that by applying the concept of elasticity / plasticity theory or viscoelasticity / viscoplaciticity theory on understanding or illustrating the observed biomedical phenomena is extremely useful to explore deep insights or enable the prediction of important biomarkers, such as glucoses, particularly for both hyperglycemic conditions (leading into various internal organ complications) and hypoglycemic conditions (insulin shock leading to possible sudden death). In this viscoelasticity study, he utilized a continuous glucose monitoring (CGM) device to collect his PPG values at each 15-minute time intervals during the 3-hour post-meal time span. His collected PPG data consist of individual data from 4,217 meals over 1,418 days, 5/8/2018 - 2/26/2022, with an average carbs/sugar intake amount of 13.68 grams per meal and an average post-meal walking of 4,251 steps per meal. He then utilizes the concept of linear elastic glucose theory as described in the following method section to construct a dataset and waveform for the LEGT PPG. A synthesized waveform of this LEGT PPG model has a shape of a "hill" which starts from a valley position at 0-minute, reaches to its maximum PPG around 60-minutes, declines back down to the valley around 120-minutes, and then remains in a relative flat level until the ending time of 180-minutes. In this article, he has used the LEGT PPG as his strain and has chosen the two following viscosity factor (η) to calculate his stress: Viscosity factor η = carbs/sugar grams of 13.68 grams & post-meal walking of 4.251 k-steps. Furthermore, the author also decides to omit detailed explanation of the basic concepts for elasticity, plasticity, viscoelasticity, viscoplasticity, and perturbation theories from the disciplines of engineering and physics in the method section. In conclusion, the author has defined his stress-strain equations as follows: Strain = ε = LEGT PPG value of each 15 minutes. Viscosity factor = η = (carbs/sugar grams of 13.68 grams * GH.p-modulus of 0.80 + post-meal walking of 4.251 k-steps * GH.w-modulus of -2.54). However, he has utilized the LEGT PPG change rate multiplied by the above described two viscosity factors to obtain two sets of stress values: Stress = η * (dε/dt) = η * (d-strain/d-time) = ((viscosity factor) * (LEGT PPG of present time - LEGT PPG of previous time) / 15)), where 15 indicates the 15-minutes time interval. Based on the stress-strain analysis in a spatial-domain (SD) and the application of the theories of viscoelasticity, viscoplasticity, and perturbation model, the following four observations are evident: (1) From a time-domain analysis (TD) of measured sensor PPG waveform and LEGT PPG waveform as well as two additional predicted LEGT PPG waveforms, it is clear that these three LEGT waveforms have extremely high correlation coefficients of 93% to 98% in comparison to the measured sensor PPG waveform. In addition, all three LEGT PPG waveforms have also reached 100% of prediction accuracies. (2) Observing the stress-strain diagram in SD, there are two stress-strain diagrams, one based on carbs/sugar amount of 13.68 grams and the other one based on post-meal walking of 4.251 k-steps as their respective viscosity factors (η). These two stress-strain diagrams are almost identical in shape except for their y-axis of stress scales are in a ratio of 3.22 to 1.0. This ratio is also the same as the ratio between these two hysteresis loop areas. (3) Since the beginning coordinates of (x=strain, y=stress) are almost connected to the ending coordinates, they demonstrate viscoelastic behaviors. (4) The range of x-axis (strain = LEGT PPG) is within 122 mg/dL and 134 mg/dL which shows his overall type 2 diabetes (T2D) conditions are well controlled, particularly where all of the PPG values are medication-free.

Keywords: Viscoelastic; Viscoplastic; Postprandial plasma glucose; Viscosity factor; Type 2 diabetes

Abbreviations: PPG: postprandial plasma glucose; FPG: fasting plasma glucose; CGM: continuous glucose monitoring; TD: time-domain; SD: spatial-domain; MPM: math-physical medicine

1. INTRODUCTION

The author has studied strength of materials and theory of elasticity through his undergraduate courses at the University of Iowa. He also conducted research work and earned a master's degree in Biomechanics under Professor James Andrews. In 1970-1971, he used a combined spring and dashpot model to simulate the behaviors of human joints, bones, muscles, and tendons (which he took some related courses at School of Medicine at UI) in order to investigate the soldier-weapon biophysical interactions during the Vietnam war era. Later, 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 structure elements. To further his education, he took additional graduate courses in various fields of fluid dynamics, thermodynamics, bridge design using energy absorption pad, and soil mechanics under earthquake forces which are dealing with "time-dependent issues".

Since then, many advancements have been made in the biomechanics branch, especially with human body live tissues that possess certain viscoelastic characteristics, such as bones, muscles, cartilages, tendons (connect bone to muscle), ligaments (connect bone to bone), fascia, and skin. For example, the author suffered plantar fasciitis for many years. He understood that calves stretch exercise or the night splint dorsiflexes forefoot, at the back of the foot, increases plantar fascia tension to offer stress-relief for the pain. This model where muscles and tendons connect the lower leg and foot is a form of viscoelastic study for medical problem solving.

When dealing with human internal organs, it is not easy to conduct live experiments to obtain accurate measurements for the biomedical material properties. Blood itself is a viscous material (time-dependent) and its viscosity factor may fall between water, honey, syrup, or gel. However, the author's research focus is on "glucose" where the blood sugar amount is produced by the liver and carried by red blood cells, not the blood itself. It is nearly impossible to measure the material geometry or material properties to determine the viscosity of "glucose" like in engineering research work.

For example, the postprandial plasma glucose (PPG) is strongly influenced by both energy input via carbs/sugar amount (~60%) and energy output via post-meal exercise level (~40%). Fundamentally, the PPG level is also dependent on the individual's health conditions in regard to liver cells and pancreatic beta cells, which produce glucose and release insulin to control the glucose level in blood. Therefore, the author selects two separate values of carbs/sugar grams and post-meal walking k-steps as the individual viscosity factor (η). Based on this knowledge, the author applies the "concept" of viscoelasticity and viscoplasticity" to construct an analogy model of time-dependent glucose behaviors.

The author's background includes mathematics, physics, and various engineering disciplines, not including biology and chemistry. He can only investigate the observed biophysical phenomena in the medical field using his ready-learned math-physical tools. For example, he studied both modern physics and quantum mechanics during his school days; therefore, he applied the theory of relativity on interactions among the organs in the human body (an inner space) which is similar to the inter-relationships among the planets in the universe (an outer space). This analogy of using the theory of relativity has been applied in medicine by the author during past few years to identify and prove the inter-connectivity of internal organs.

By utilizing the perturbation theory, he was able to obtain an approximate but accurate predicted glucose level along with the estimation for the associated energy of glucose.

In addition, he conducted some investigations on glucose behaviors using elasticity theory and plasticity theory (both static and dynamic), which allowed him to write a few articles on his research findings. In his previous research work using linear elastic glucose theory (LEGT), he has developed two GH-Modulus, GH.p and GH.w as two modification factors or weighting factors for food and exercise, two major influences on PPG values.

Recently, the author has received an email from Professor Norman Jones, his academic advisor at MIT. Professor Jones wrote that: "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 emphasized the time-dependence of various behaviours in the body. Just a thought." His suggestion has triggered the author's strong interest and desire to research this subject on glucose behaviors further by using the viscosity theory.

Nevertheless, the medical field is still quite different from the engineering field, where the engineering materials such as steel, copper, concrete, and aluminum are inorganic 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 cells are organic and go through many distinct stages over their natural lifespans, such as birth, splitting, growth, development, mutation, repair, sickness, and death. Therefore, the biomedical properties are "moving targets" which vary with the individual person, severity of diseases, and selected different time-windows. In other words, they are both time-dependent and specimen-dependent. Furthermore, some basic engineering material characteristics, such as calculations for the cross-section of a subject, bending moment of resistance, or the shape factors in solid mechanics, are not applicable in this biomedical glucose analogy study of elasticity/plasticity or viscoelasticity/viscoplasticity. In the author's opinion, the most important part is that by applying the concept of elasticity or plasticity theory or viscoelasticity or viscoplaciticity theory on understanding or illustrating the observed biomedical phenomena is extremely useful to explore deep insights or enable the prediction of important biomarkers, such as glucoses, particularly for both hyperglycemic conditions (leading into various internal organ complications) and hypoglycemic conditions (insulin shock leading to possible sudden death).

In this particular viscoelasticity study, he utilized a continuous glucose monitoring (CGM) device to collect his PPG values at each 15-minute time intervals during the 3-hours of post-meal timespan. His collected PPG data consist of individual data from 4,217 meals of 1,418 days (5/8/2018 - 2/26/2022) with an averaged carbs/sugar intake amount of 13.68 grams per meal and an averaged post-meal walking of 4,251 steps per meal.

He then utilizes the concept of linear elastic glucose theory as described in the following section of Method to construct a dataset and waveform of his LEGT PPG. This LEGT PPG model has a shape of a "hill" which starts from a valley position at 0-minute, reach to its maximum PPG around 60-minutes, decline back to the valley around 120-minutes, and tan remain in a relative flat level until the ending time of 180-minutes.

In this article, he has used the LEGT PPG as his strain and has chosen his two following viscosity factor (η) to calculate his stress:

Viscosity factor η
= carbs/sugar grams of 13.68 grams & post-meal walking of 4.251 k-steps

Furthermore, in this article, the author also decides to omit detailed explanation of the basic concepts for elasticity, plasticity, viscoelasticity, viscoplasticity, and perturbation theories from the disciplines of engineering and physics in the method section.

2. METHODS

2.1 Highlights of linear elastic glucose theory

Here is the step-by-step explanation for the predicted PPG equation using linear elastic glucose theory as described below:

(1) Baseline PPG equals to 1.16 * FPG value. This 116% is the GH.f-modulus.

(2) Baseline PPG plus increased amount of PPG due to food intake, i.e., plus (carbs/sugar intake amount * GH.p-modulus of 0.80).

(3) Baseline PPG plus increased PPG due to food, and then subtracts reduction amount of PPG due to exercise, i.e., minus (post-meal walking k-steps * GH.w of 2.54).

(4) The predicted LEGT PPG equals to baseline PPG plus the food influences, and then subtracts the exercise influences.

The linear elastic glucose theory (LEGT) generated PPG equation is:

Predicted PPG
= (FPG * GH.f-modulus of 1.16) + (Carbs&sugar grams * GH.p-modulus of 0.80) - (post-meal walking k-steps * GH.w-modulus of 2.54)

Where,

(1) Incremental PPG = predicted PPG - baseline PPG + exercise impact
(2) GH.f-modulus = FPG / weight
(3) GH.p-modulus = increased PPG, i.e., energy infusion from carbs/sugar intake
(4) GH.w-modulus = decreased PPG, i.e., energy consumption from post-meal exercise.

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 background information during the period from 8/8/2018 to 2/25/2022 which include PPG, FPG, Carbs/sugar amount, and post-meal walking k-steps.

Figure 2 depicts the data table and calculation results of this study.

Figure 3 reflects TD comparison between the measured sensor PPG versus LEGT PPG and two predicted LEGT PPG.

Figure 4 illustrates a Viscoelastic stress-strain diagram of two predicted LEGT PPG with two different viscosity factors.

Figure 5 displays a combined stress-strain diagram of two different stress components based on carbs/sugar grams and walking k-steps, respectively.

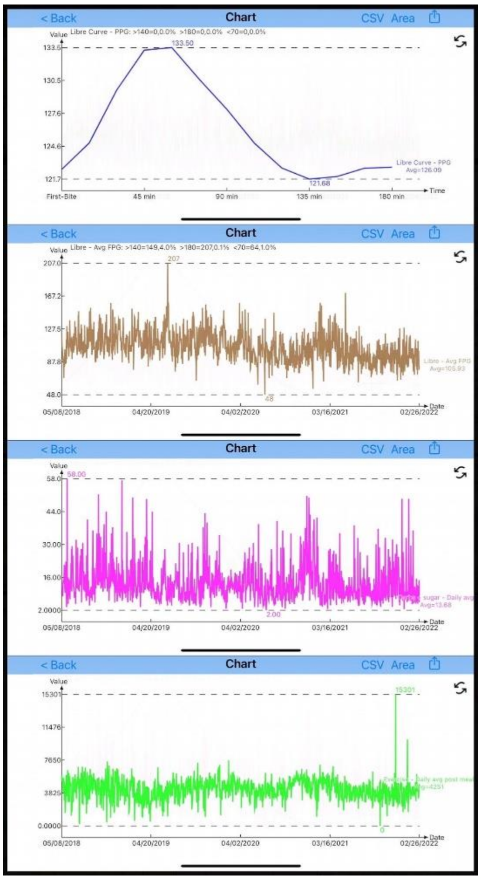

Figure 1: Background information during the period from 8/8/2018 to 2/25/2022.

2/27/22	FPG	GH.f	Carbs/Sugar	GH-p	K-Steps	GH.w	Carbs + Ksteps
	105.93	1.16	13.68	0.80	4.251	-2.54	0.15
						Carbs / Ksteps	3.22
PPG Study	**Measured PPG**	**LEGT PPG**	**Stress (Carbs)**	**Pred. PPG (carbs)**	**LEGT PPG**	**Stress (Ksteps)**	**Pred. PPG (Ksteps)**
0 min	123	123	0.00	123	123	0.00	123
15 min	125	125	2.50	128	125	0.78	126
30 min	130	128	2.50	131	128	0.78	129
45 min	133	131	2.50	133	131	0.78	132
60 min	134	134	2.50	136	134	0.78	134
75 min	131	131	-2.46	128	131	-0.77	130
90 min	128	128	-2.46	126	128	-0.77	127
105 min	125	125	-2.46	123	125	-0.77	125
120 min	123	123	-2.46	120	123	-0.77	122
135 min	122	123	0.00	123	123	0.00	123
150 min	122	123	0.00	123	123	0.00	123
165 min	123	123	0.00	123	123	0.00	123
180 min	123	123	0.00	123	123	0.00	123
Average	126.1	126.0	0.01	126.0	126.0	0.00	126.0
Correlation		98%		93%			98%
Accuracy		100%		100%			100%

Figure 2: Data table and calculation results of this study.

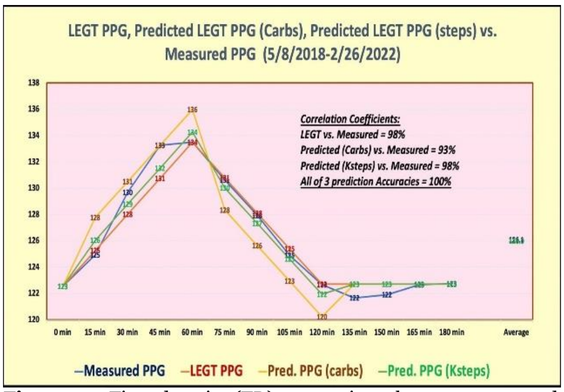

Figure 3: Time-domain (TD) comparison between measured sensor PPG versus LEGT PPG and two predicted LEGT PPG.

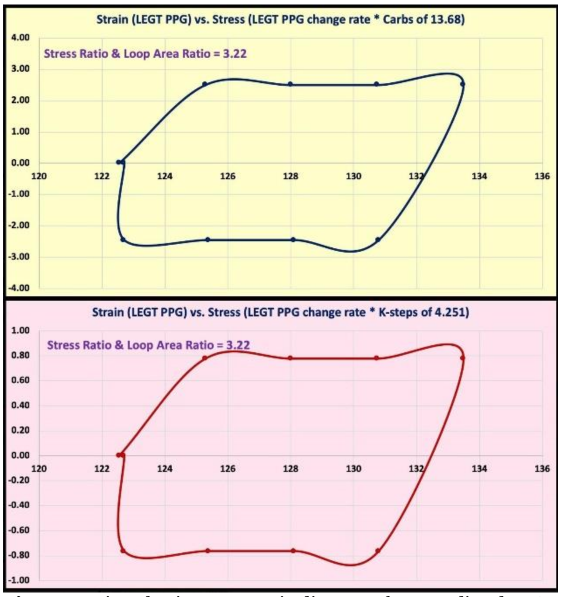

Figure 4: Viscoelastic stress-strain diagram of two predicted LEGT PPG with two different viscosity factors.

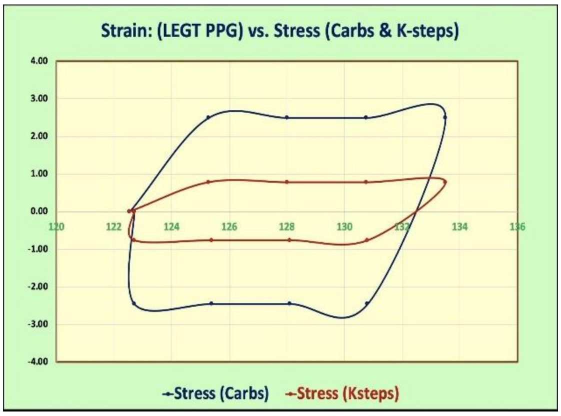

Figure 5: A combined stress-strain diagram of two different stress components based on carbs/sugar and walking k-steps, respectively.

4. CONCLUSION

In conclusion, the author has defined his stress-strain equations as follows:

Strain
= ε
= LEGT PPG value of each 15 minutes

Viscosity factor
= η
= (carbs/sugar grams of 13.68 grams * GH.p-modulus of 0.80 + post-meal walking of 4.251 k-steps * GH.w-modulus of -2.54)

However, he has utilized the LEGT PPG change rate multiplied by the above described two viscosity factors to obtain two sets of stress values:

Stress
= η * (dε/dt)
= η * (d-strain/d-time)
= ((viscosity factor) * (LEGT PPG of present time - LEGT PPG of previous time) / 15))

Where 15 indicates the 15-minutes time interval.

Based on the stress-strain analysis in a spatial-domain (SD) and the application of the theories of viscoelasticity, viscoplasticity, and perturbation model, the following four observations are evident:

(1) From a time-domain analysis (TD) of measured sensor PPG waveform and LEGT PPG waveform as well as two additional predicted LEGT PPG waveforms, it is clear that these three LEGT waveforms have extremely high correlation coefficients of 93% to 98% in comparison to the measured sensor PPG waveform. In addition, all three LEGT PPG waveforms have also reached 100% of prediction accuracies.

(2) Observing the stress-strain diagram in SD, there are two stress-strain diagrams, one based on carbs/sugar amount of 13.68 grams and the other one based on post-meal walking of 4.251 k-steps as their respective viscosity factors (η). These two stress-strain diagrams are almost identical in shape except for their y-axis of stress scales are in a ratio of 3.22 to 1.0. This ratio is also the same as the ratio between these two hysteresis loop areas.

(3) Since the beginning coordinates of (x=strain, y=stress) are almost connected to the ending coordinates, they demonstrate viscoelastic behaviors.

(4) The range of x-axis (strain = LEGT PPG) is within 122 mg/dL and 134 mg/dL which shows his overall type 2 diabetes (T2D) conditions are well controlled, particularly where all of the PPG values are medication-free.

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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Viscoelastic and Viscoplastic Glucose Theory Application in Medicine

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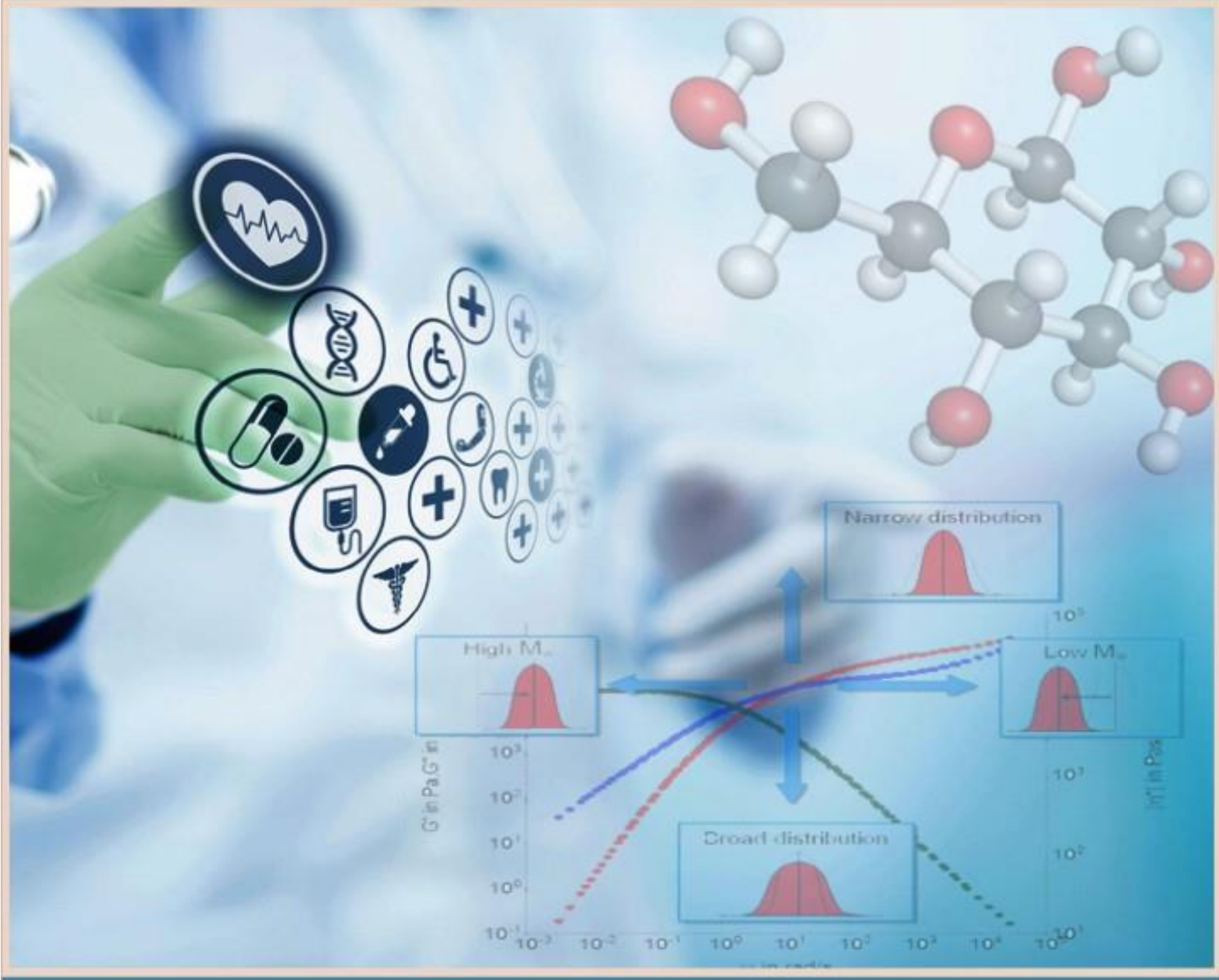

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