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The GH-Method

Viscoelastic and Viscoplastic Glucose Theory (VGT #33): Applying VGT and Viscoelastic Perturbation Model and Using the Combined Values from Carbs/Sugar Intake Amount with GH.p-Modulus and Post-Meal Walking k-Steps with GH.w-Modulus as the Constant Viscosity Factor to Predict the K-line PPG Values from 8/8/2018 to 2/25/2022 Based on GH-Method: Math-Physical Medicine (No. 614)

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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 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 a combined value of (carbs/sugar grams and post-meal walking k-steps with 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

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(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 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. The two GH-Moduli, GH.p and GH.w, are the results from his earlier research work of applying linear elastic glucose theory (LEGT) to diabetes using the theory of elasticity from physics and engineering. 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, 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 / viscoplasticity 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. This output variable for the K-line PPG consists of data from 3,912 meals over 1,297 days with an average carbs/sugar intake amount of 13.56 grams per meal and an average post-meal walking of 4,233 steps per meal. Due to the big size of input data from 1,297 days, the author will only show the key results of the calculations and will not include the daily data table in this article. He then utilizes the concept of candlestick model (aka "K-line model" as described in the following Method section) from Wall Street to construct a dataset and waveform of K-line PPG. This K-line PPG model looks like a candlestick which contains 5 key data, starting PPG at 0-minute, maximum PPG usually around 60-minutes, minimum PPG usually around 120-minutes, ending PPG at 180-minutes, and average PPG. In this article, he defines the K-line PPG value as: K-line PPG = (starting PPG + maximum PPG + minimum PPG + ending PPG) / 4. The chosen viscosity factor (η) is: Viscosity factor η = (carbs/sugar grams of 13.56 grams * GH.p-modulus of 3.22 + post-meal walking of 4.233 k-steps * GH.w-modulus of -5.0). Furthermore, the author omits a 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, he has defined his stress-strain equations as follows: Strain = ε = K-line PPG value of each day. Viscosity factor = η = (carbs/sugar grams of 13.56 grams * GH.p-modulus of 3.22 + post-meal walking of 4.233 k-steps * GH.w-modulus of -5.0) = 22.5. However, he has utilized the K-line PPG change rate multiplied by the above-described viscosity factor of 22.5 to obtain the stress values: Stress = η * (dε/dt) = η * (d-strain/d-time) = ((viscosity factor) * (K-line PPG of present day - K-line PPG of previous day) / 24)); where 24 indicates the 24-hour time span of each day. 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 three observations are evident: (1) From a time-domain analysis (TD) of PPG waveform chart, K-line PPG chart and a SD analysis of stress-strain chart, it is clear that each different diagram can reveal different phenomena, characteristics, and messages. (2) Observing from the stress-strain diagram in SD, the K-line PPG using the combined carbs/sugar and post-meal exercise as the constant viscosity factor (η) shows a complete picture of PPG but with a rather complicated graphic representation of the 1,297 datasets. However, if we delve into the details, we can still identify the following three key phenomena: (a) during the 2020-2022 COVID quarantine period, most of the strain (K-line PPG) values are less than 115 mg/dL i.e., normal condition, and also with a lower glucose fluctuation (GF) about 20% - 25% lower in the GF magnitude for the pre-COVID period. (b) during the 2018-2019 pre-COVID period, most of the strain (K-line PPG) values are higher than 130

mg/dL i.e., pre-diabetic condition, and also with a high GF about 20% - 25% higher in the GF magnitude for the COVID period. (c) the strain values on the x-axis show the K-line PPG values while the strain rate values (with a constant viscosity factor) on the y-axis reflect the K-line PPG GF rate values. It is important to know that the higher GF level associates with a higher energy level and causes more damage to the internal organs. (3) Both the predicted K-line PPG and the calculated K-line PPG values using the viscoelastic perturbation method have achieved extremely high prediction accuracy of 99% and equally high correlation coefficient of 99% in comparison with the measured sensor PPG data and waveform.

Keywords: Viscoelastic; Viscoplastic; Body weight; Body temperature; Viscosity factor; Type 2 diabetes

Abbreviations: PPG: postprandial plasma glucose; FPG: fasting plasma glucose; CGM: continuous glucose monitoring; TD: time-domain; SD: spatial-domain; GF: glucose fluctuation; 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 (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".

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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 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 a combined value of (carbs/sugar grams and post-meal walking k-steps with 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.

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By utilizing the perturbation theory from quantum mechanics, 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. The two GH-Moduli, GH.p and GH.w, are the results from his earlier research work of applying linear elastic glucose theory (LEGT) to diabetes using the theory of elasticity from physics and engineering.

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, 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. This output variable for the K-line PPG consists of data from 3,912 meals over 1,297 days with an average carbs/sugar intake amount of 13.56 grams per meal and an average post-meal walking of 4,233 steps per meal.

Due to the big size of input data from 1,297 days, the author will only show the key results of the calculations and will not include the daily data table in this article.

He then utilizes the concept of candlestick model (aka "K-line model" as described in the following Method section) from Wall Street to construct a dataset and waveform of K-line PPG. This K-line PPG model looks like a candlestick which contains 5 key data, starting PPG at 0-minute, maximum PPG usually around 60-minutes, minimum PPG usually around 120-minutes, ending PPG at 180-minutes, and average PPG. In this article, he defines the K-line PPG value as:

K-line PPG
= (starting PPG + maximum PPG + minimum PPG + ending PPG) / 4

The chosen viscosity factor (η) is:

Viscosity factor η
= (carbs/sugar grams of 13.56 grams * GH.p-modulus of 3.22 + post-meal walking of 4.233 k-steps * GH.w-modulus of -5.0)

Furthermore, the author omits a 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 97% of FPG value, or 97% * (weight * GH.f-modulus).

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

(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 * 5).

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

The linear elastic glucose equation is:

Predicted PPG
= (0.97 * GH.f-modulus * weight) + (GH.p-modulus * carbs&sugar) - (post-meal walking k-steps * 5)

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.

2.2 Candlestick (aka K-line) model

A Japanese merchant, who traded in the rice market in Osaka, Japan, started the candlestick charting around 1850. Steve Nison, an American, brought the candlestick model concept and method to the Western world in 1991. These techniques are largely used in today's stock market to predict the stock price trend.

On 4/17/2018, the author had an idea to study glucose behavior by using the candlestick chart (aka "K-Line") and subsequently developed a customized software to analyze his big data of glucose. The analogies between fluctuations of stock price and glucose value are described as follows:

(1) Stock prices are closely related to the psychology of the buyers and sellers, which is similar to the glucoses related to a patient body's biochemical interactions and behavior psychology.

(2) Stock price wave of a publicly traded company is dependent upon its product line, internal management, marketing efforts, and public events and perception. This is remarkably similar to the PPG wave of a diabetes patient being dependent on his/her complex food & diet (buying stock), exercise pattern and amount (selling stock), weather temperature (buying stock), and pancreatic beta cell insulin function (SEC regulations). From a trained mathematician's eyes, both waves are just two similar mathematical representations.

(3) When there are more buyers than sellers, the price goes up, which is similar to the glucose value rising when carbs/sugar intake increases (more buyers) or lack of exercise (less sellers).

(4) When there are more sellers than buyers, price goes down, which is similar to the glucose value decreasing when carbs/sugar intake decreases (less buyers) or exercise increases (more sellers).

His standard PPG wave covers 13 data points (every 15 minutes) and 37 data points (every 5 minutes) for a period of 180 minutes, or 3-hours, from the first-bite of his meal. Each PPG waveform contains the following five key characteristic data:

1. "Open" value as his PPG at first-bite, or 0 minute
2. "Close" value as PPG at 180 minutes
3. "Minimum" value as the lowest PPG
4. "Maximum" value as the highest PPG
5. "Average" glucose - average value of 12 recorded PPG data per meal over 3-hours

Based on his meal's candlestick bars, glucose patterns and moving trends can also be observed and analyzed through further mathematical and statistical operations. Finally, he interpreted these operational results with his acquired knowledge of biomedical phenomena of his body in order to discover some hidden medical truth or potential health dangers via TIR/TAR/TBR analysis.

Since the stock market is much more lucrative than the medical research field, it attracts more talented mathematicians and engineers to work in the highly rewarded financial industry. They even call themselves, "Finance Engineers". On the contrary, most financial rewards in the medical community are distributed to pharmaceutical companies, healthcare institutions, and clinical medical doctors.

From the author's personal observation, a large number of medical research scientists are self-motivated through their interests and dedication, which are mostly associated with either universities or research institutions. They are rarely rewarded financially.

The author is a professionally trained mathematician, physicist, engineer, computer scientist, and a successful entrepreneur. He accidentally wandered into the medical research field due to his strong motivation of saving his own life after suffering many diabetes complications and faced the possibility of death. As a result, he thought about how to import his learned physics principles and theories, mathematical analysis methods, engineering modeling techniques from his academic educations and professional experiences, as well as his accumulated knowledge regarding stock price and other financial analyses techniques, such as the Candlestick model, from his position as the CEO of a publicly traded corporation, and apply them to his medical research activities. This allowed him to learn and gain medical insights from using his knowledge of financial world intellectual properties (IP) and professional and industrial working experiences.

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 definition of his K-line PPG with a synthesized PPG waveform and candlesticks during the long period of ~3.5 years from 8/8/2018 to 2/25/2022.

Figure 2 depicts a Viscoelastic stress-strain diagram of calculated K-line PPG with a constant viscosity factor of 22.5. The key observations are explained in the conclusion section.

Figure 3 reveals the comparison of measured sensor PPG versus both of the defined and the predicted K-line PPG via the viscoelastic perturbation model. The prediction accuracies are 99% and the correlation coefficients are 99% as well.

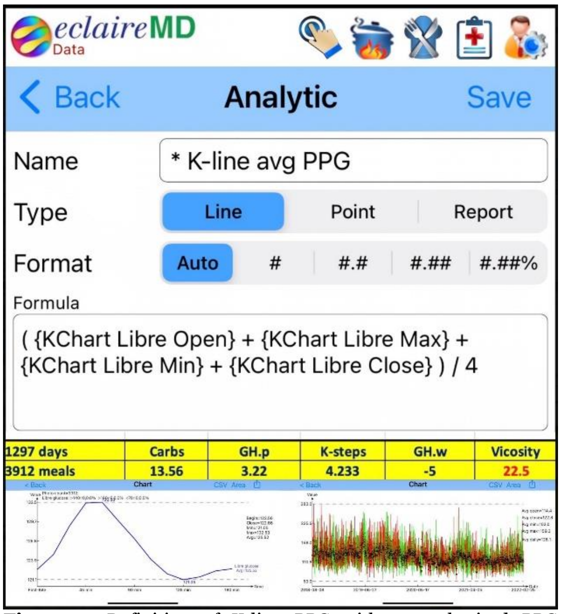

Figure 1: Definition of K-line PPG with a synthesized PPG waveform and candlesticks during the period from 8/8/2018 to 2/25/2022.

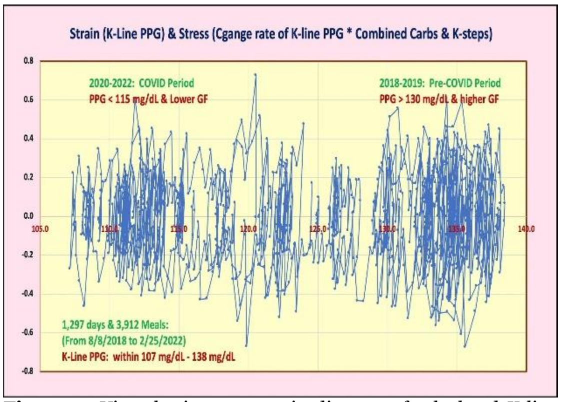

Figure 2: Viscoelastic stress-strain diagram of calculated K-line PPG with a constant viscosity factor of 22.5.

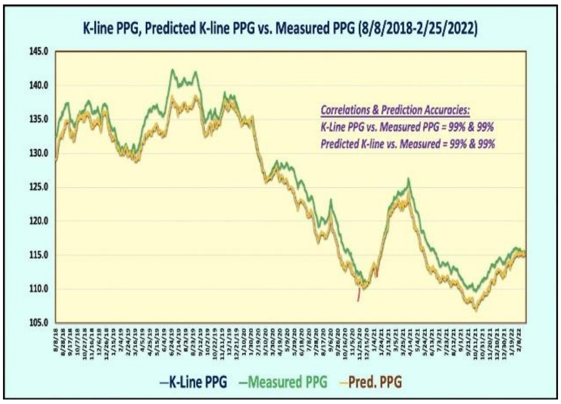

Figure 3: Time-domain (TD) comparison between measured sensor PPG versus both the defined and predicted K-line PPG using the viscoelastic perturbation model.

4. CONCLUSION

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

Strain
= ε
= K-line PPG value of each day

Viscosity factor
= η
= (carbs/sugar grams of 13.56 grams * GH.p-modulus of 3.22 + post-meal walking of 4.233 k-steps * GH.w-modulus of -5.0)
= 22.5

However, he has utilized the K-line PPG change rate multiplied by the above-described viscosity factor of 22.5 to obtain the stress values:

Stress
= η * (dε/dt)
= η * (d-strain/d-time)
= ((viscosity factor) * (K-line PPG of present day - K-line PPG of previous day) / 24))

Where 24 indicates the 24-hour time span of each day.

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 three observations are evident:

(1) From a time-domain analysis (TD) of PPG waveform chart, K-line PPG chart and a SD analysis of stress-strain chart, it is clear that each different diagram can reveal different phenomena, characteristics, and messages.

(2) Observing from the stress-strain diagram in SD, the K-line PPG using the combined carbs/sugar and post-meal exercise as the constant viscosity factor (η) shows a complete picture of PPG but with a rather complicated graphic representation of the 1,297 datasets. However, if we delve into the details, we can still identify the following three key phenomena: (a) during the 2020-2022 COVID quarantine period, most of the strain (K-line PPG) values are less than 115 mg/dL i.e., normal condition, and also with a lower glucose fluctuation (GF) about 20% - 25% lower in the GF magnitude for the pre-COVID period. (b) during the 2018-2019 pre-COVID period, most of the strain (K-line PPG) values are higher than 130 mg/dL i.e., pre-diabetic condition, and also with a high GF about 20% - 25% higher in the GF magnitude for the COVID period. (c) the strain values on the x-axis show the K-line PPG values while the strain rate values (with a constant viscosity factor) on the y-axis reflect the K-line PPG GF rate values. It is important to know that the higher GF level associates with a higher energy level and causes more damage to the internal organs.

(3) Both the predicted K-line PPG and the calculated K-line PPG values using the viscoelastic perturbation method have achieved extremely high prediction accuracy of 99% and equally high correlation coefficient of 99% in comparison with the measured sensor PPG data and waveform.

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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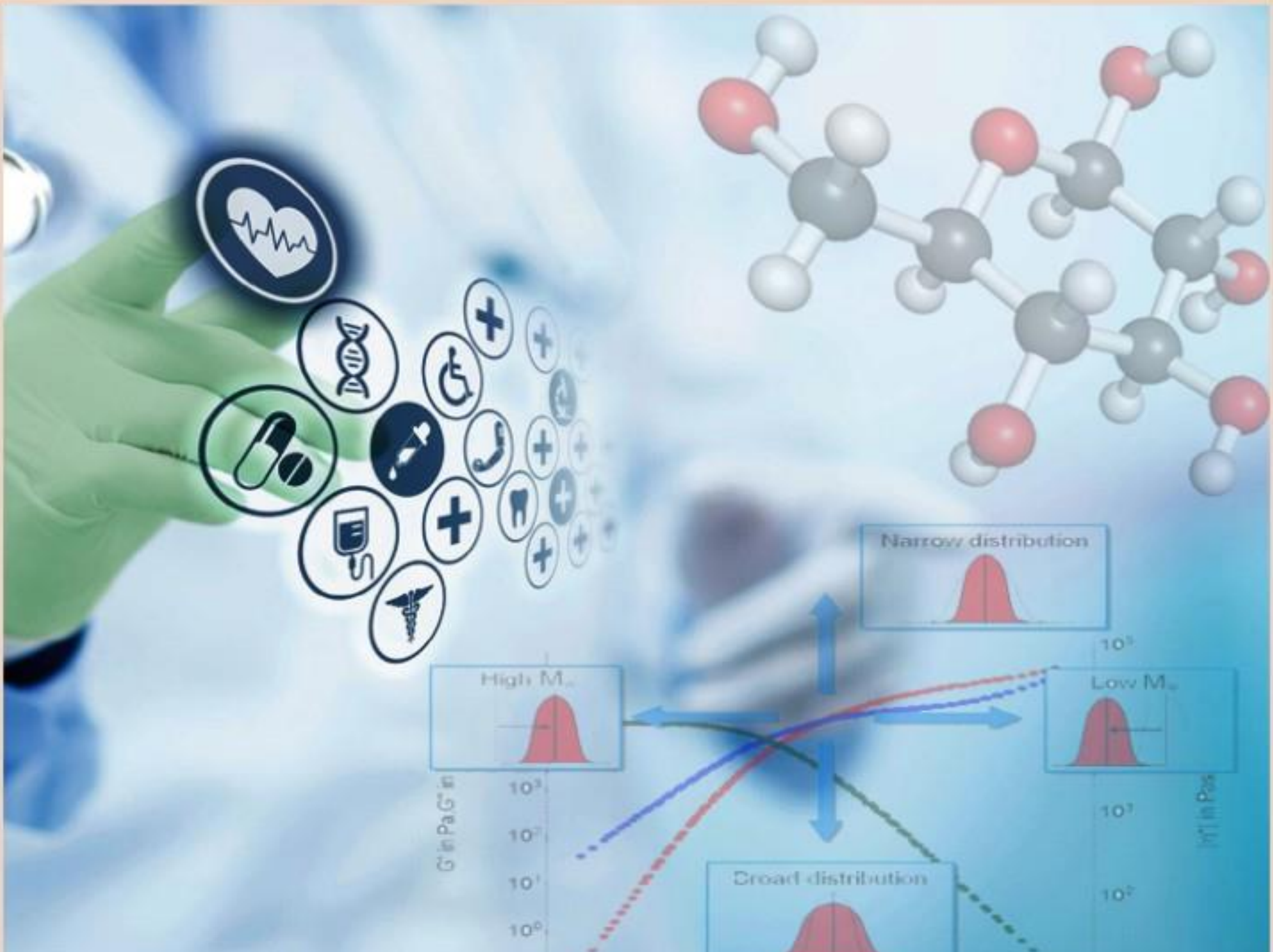

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