

The Application of Engineering Principles to Health and Wellness

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ABSTRACT

Professionally, health and wellness is usually the concern of health and medical practitioners. However, the analogy and similarity between biological and engineering systems are striking that engineers become interested in studying potential applications. The human body is more complicated than many engineering systems, and applying engineering principles to the human body can logically improve its performance. In this paper, five major principles (mass balance, energy balance, momentum balance, charge balance, and moment balance) are applied to the human body. About 2 dozen auxiliary principles (fundamentals usually studied in physics and chemistry) supplement the major principles. Examples of practical applications are discussed. However, direct applications of some principles may not be simple and have some limitations. Genetic makeup, environmental factors, and lifestyle practices largely affect the performance of the human body. A more realistic alternative is to apply the principle of preventive maintenance of engineering systems to the human body. This will result in a well functioning and healthy body.

We possess an intricate machine (the body) and a powerful computer (the brain) but we do not get an “owner’s manual” to operate them. The government should at least provide a basic manual that every person can follow. Of course, every person has his free will and consciousness, which make the human body superior than engineering systems at present.

Introduction

The human body is a marvelous machine and computer, which is self-reproducing and possesses free will. Generally, this biological system behaves like an engineering system and we can apply scientific and engineering principles to understand it better. This paper is about the application of engineering principles to promote health and wellness of the human body. We depend on the experts (medical doctors, nurses, health and wellness professionals, etc.) to take care of our health. However, most people do not entirely follow the advice to maintain their body. On the other hand, everybody is responsible for his own body. Many of us do not entirely follow the suggestions and recommendation mainly due to lack of knowledge and information. Health problems are usually caused by ignorance or nonchalance.

Engineers have traditionally been involved in the medical field, such as bioengineering, biomedical engineering, biomechanics, bioelectronics, and related fields. The results of their work form a body of advanced knowledge that has supplemented the traditional areas with improvements and innovations. On more practical applications, engineers are involved in the medical industry. They help sustain the business viability of health care systems and maintain medical facilities and infrastructure.

The health and wellness industry is a growing industry. In the US alone, sales have reached \$200 billion in 2002 and was projected to reach \$1 trillion this year. [Kickbusch and Payne, 2003] Therefore, the situation presents opportunities to engineers. For engineers to

enter this field, they have to change their perspective. The health and wellness field has a paradigm that is different from the ones engineers usually deal with. It will require them to take some background studies and retooling. Thus this paper introduces the field of health and wellness engineering.

Translating knowledge about the human body to health and wellness terms

The body of knowledge about the human body is diverse and encompasses a range of practices that have evolved to maintain and restore health. Medical physics, which refers to the application of the principles of physics to the understanding of the function of the human body in health and disease, can provide us enough information about the human body. [Cameron et al., 1999] According to the constitution of the World Health Organization, health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity. [WHO, 2010] Since the sense of feeling well and prevention of sickness are the essence of health and wellness, the usual medical approach may yield a negative effect on some people concerned. Therefore, other methods to deal with the subject may be preferred. For example, as in this paper, health and wellness is presented in the point of view of an engineer. I present my ideas based on actual personal experiences. However, the situation is not as simple as we envision. To delve on a topic outside one's field of expertise may be preposterous. Fortunately, knowledge integration and organization has been my interest in the past years. By probing paradigms, I am able to interconnect ideas and view paradigms in a different perspective. In this paper, using available knowledge, especially about physics of the body and physiology, I make direct analogies from an engineering perspective. In this case, some ideas not considered before may come out, or some of the ideas may be more convincing than the usual way. While health comprises spiritual, mental, and physical aspects, this paper considers mainly physical and partly mental issues, but not the spiritual side.

As an engineer with some knowledge of biological systems, I will consider the human body as an engineering system and apply some engineering principles. Studying the human body may require the use of modeling. We consider a model as a representation of a phenomenon. We can have physical models such as that for a building, an airplane, a car or even the solar system. In science and engineering mathematical models are more common. Equations represent the phenomena.

Modeling Biological Systems

The first limitation that we encounter when modeling the human body is that we have to deal with a complex biological system. This means that the chemistry and biochemistry of the body have to be considered. As we can see, this will inevitably be in the domain of medical science and biology. However, we will keep the discussion simpler and avoid complications in traversing other fields. The information about the human body as we see it today is the result of numerous studies and investigations. The smallest component, the cell, has been modeled based on the results of studies of single-cell organisms such as the bacteria. The cellular components and functions are similar. Therefore, they are relevant when we study the human body.

When we model biological systems, we normally start with the growth rate. Because of the diversity of organisms, modeling their growth in a single framework is seemingly impossible. We can use hundreds of parameters and we would not even come up with a comprehensive model. What this tells us is that while the subject of this paper is difficult, having a simple model

will make us understand the functioning of the human body better. Our major interest should be the interaction of the human body with the environment and other biological systems.

Modeling in Science and Engineering

Modeling is not normally taken as a formal subject in science and engineering; it is equivalent to applied mathematics. Partly because of less emphasis, many students find mathematical modeling quite difficult. The difficulty lies in the perception that many principles have to be understood and applied. In reality, we need only three major laws (for the human body we need five) and about two dozen auxiliary relationships. (Basmadjian, 2000) The discussion on health and wellness will be based on simplified models. The human body as a biological system consists of a physical body with mind and soul, possessing consciousness and free will. Health concerns the physical, mental and emotional, social and spiritual aspects. Only the physical and mental aspects are considered in this paper.

Five Major Laws and Two Dozen Auxiliary Principles

The five major principles for modeling engineering systems are:

- Law of Conservation of Mass
- Law of Conservation of Energy
- Law of Conservation of Momentum
- Law of Conservation of Charge
- Law of Conservation of Moment

The above principles can adequately be used to describe the human body in the same manner as engineering systems and other biological systems. In doing so, another perspective in presenting health and wellness principles may evolve that can further help in the promotion wellness concerns.

To simplify the basic balances, they have to be expressed in terms of secondary variables and parameters. We have to use about two dozen auxiliary relations drawn from subdisciplines such as kinetics, thermodynamics, transport theory, and fluid mechanics. The parameters contained in these relations are often determined experimentally. In this paper, we limit the discussion to the five major principles in a quantitative manner.

Law of Conservation of Mass (Mass Balance)

The equation for combined molecular and convected fluxes is given by

$$\frac{\partial}{\partial t} \rho \omega_A = -(\nabla \cdot \mathbf{n}_A) + r_A$$

where

ρ = density

ω_A = mass fraction of species A

\mathbf{n}_A = combined mass flux vector for species A

r_A = mass rate of production of species a by chemical reactions

t = time

This law is relevant to the amount of food we take, the type of food, and other inputs we take in voluntarily or involuntarily (medicine, drugs, pollution, alcohol, cigarette smoking, etc.). Likewise, the formation of substances and the reaction within the body can be considered with this law. Mass balances around the systems and organs within a body can be set up.

Law of Conservation of Energy

The equation for combined molecular and convected fluxes is given by

$$\frac{\partial}{\partial t} \rho(\hat{U} + \frac{1}{2}v^2) = -[\nabla \cdot \mathbf{e}] + \rho(\mathbf{v} \cdot \mathbf{g})$$

where

- ρ = density
- \hat{U} = internal energy
- \mathbf{e} = combined energy flux vector
- \mathbf{v} = mass average velocity
- \mathbf{g} = gravitational acceleration
- t = time

The energy of the body is very important. Every activity in the body, including thinking, consumes energy. Energy derived from food is the principal source of energy and each system in the body requires energy in order to function. The energy is converted to other forms and ultimately dissipated as heat. The law in this section encompasses energy, heat, work, and power of the body.

Law of Conservation of Momentum

The equation for combined molecular and convected fluxes is given by

$$\frac{\partial}{\partial t} \rho \mathbf{v} = -[\nabla \cdot \Phi] + \rho \mathbf{g}$$

where

- ρ = density
- \mathbf{v} = mass average velocity
- Φ = combined momentum flux tensor
- \mathbf{g} = gravitational acceleration
- t = time

Materials such as air, blood, water, and other fluids flow within the human body and possess momentum. Momentum balance is important in maintaining such flow within favorable conditions. The law in this section is important in the maintenance of proper pressures within the different parts of the human body.

Law of Conservation of Charge

Charge conservation is the principle that electric charge can neither be created nor destroyed and represented by the equation,

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot \mathbf{J}$$

where

- ρ = charge density
- \mathbf{J} = electric current density
- t = time

The law of conservation of charge states that the net charge of an isolated system remains constant. This is also known as Kirchhoff's Law. The charge of the human body must remain

neutral. Any deviation (too positive or too negative) indicates disease and unwellness. Cells, organs, and systems of the body communicate through charges. The brain is the center of communication, which is the nervous system. A balance of charge is very important.

Law of Conservation of Angular Momentum

The angular momentum balance equation can be stated as:

Moment of external Force = Local rate of change of moment of momentum inside control volume + net moment of momentum flux across the control surface

and symbolically by

$$\mathbf{r} \times \mathbf{F} = \frac{\partial}{\partial t} \int_{CV} (\rho \mathbf{r} \times \mathbf{v}) dV + \int_{CS} (\rho \mathbf{r} \times \mathbf{v}) \mathbf{v} \cdot d\mathbf{A}$$

where \mathbf{r} = position vector with respect to the origin

\mathbf{F} = force

ρ = density

\mathbf{v} = velocity

V = volume

A = area

CV = control volume

CS = control surface

The law in this section is important for the human body on the aspects of body movement, exercises, forces to the body, structural strength of the body, balance and equilibrium, and response to the force of gravity.

Mass Balance in Biological Systems

Typically in a living organism, the mass balance setup contains the elements of organic compounds: carbon, hydrogen, oxygen, and nitrogen. We can express the mass in terms of a stoichiometric formula such as $\text{CH}_a\text{O}_b\text{N}_c$. Aside from the major elements, we also have to include sulfur, chlorine, sodium, magnesium, potassium, calcium, and some other fourteen trace elements. The food taken in by the system is converted to feces and the rest assimilated by the body and added to the reserves. The reserves fuel the metabolic processes, which include the synthesis of body mass, synthesis of gametes, and other processes.

Conservation of Mass

While we will discuss plain mass balance, our emphasis is on the effect of the inputs and outputs of the human body. The mass balance equation is represented by

$$\frac{dm}{dt} = \text{input} - \text{output}$$

where m is the mass and t , time.

Using concentration c ,

$$V \frac{dc}{dt} = \text{input} - \text{output}$$

where V is the volume.

With formation and transformation terms included,

$$V \frac{dc}{dt} = \text{input} - \text{output} + \text{formation} - \text{transformation}$$

Inputs to and outputs from the Body

The necessary inputs to the body are food and water. Sometimes, we take in substances that may be harmful to the body such as alcohol, caffeine, cigarettes, drugs (cocaine, heroine, and marijuana). When we are sick, we take medicine that may or may not have side effects.

The major outputs of the body are the feces and urine. Perspiration is also an output. We shed some parts of the body such as hair, nail, old skin, etc. We may lose some body liquid such as blood when skin is ruptured.

The formation of harmful or helpful compounds in the body is a major concern. The transformations in the body are those that are necessary to life processes.

The food we take is used for respiration, growth and reproduction. We excrete feces that consist of digested food, wastes, and undigested food. If the net products = growth + reproduction,

$$\text{net products} = \text{intake of food} - \text{respiration} - \text{excretion} - (\text{wasted and undigested food})$$

We consider the human body as a semi-batch flow system.

The purpose of taking in food is usually for nutrition. We need food for health and energy to live comfortably. Basically, we need carbohydrates, proteins, fats, vitamins, and minerals. We require a lot of water. We have to be concerned with the type of food we take in. Some food we take may contain toxic substances with or without our knowledge. For example, some food may be contaminated with harmful pesticides, radioactive compounds, or pathogenic microorganisms. Some food contains caffeine, nicotine or other drugs with our knowledge of the objective of getting a different feeling. Some toxic compounds accumulate with age and eventually cause failure of body functioning.

The field of nutrition is so confusing that choosing a diet is difficult. Some diet advocates high protein intake and low carbohydrates. Some have particular ratios and time of intake of particular substances. In some instances, food manufacturers are accused of conspiracy because of their desire to rake in profits. What food should we take then? We can follow medical advice that is supported by sound studies and research. For example, a good diet should consist of up to 70% fruits and vegetables. Usually the minerals and vitamins come with the food we eat. In case of deficiency, we can take medically approved supplements. Human bodies are different from another. On the one hand, some people take as much food they want and maintain a lean figure.

On the other hand, some people gain weight by taking only small portions of food. Our state of health is usually a reflection of our eating habits. Indiscriminate intake of some types of food can cause disease such as heart disease and hypertension. We cannot make generalizations on the food intake but a balanced diet recommended by nutritionists is sometimes necessary. The cholesterol content and the type of fat in our food should also be considered. Let us turn to an input we should particularly take note of: the enzymes in our food. Enzymes are proteins that catalyze biochemical reactions. They are involved in every metabolic process in our body.

Enzymes perform some of these functions:

1. They aid in digesting food. They build muscles, nerves, glands, and proteins in skin and bones.
2. They assist in storing sugar. They turn fat into fatty tissue. They help absorb iron in a fatty tissue.
3. They aid in detoxifying the body of unwanted substances.

Theoretically, our body can supply most of the necessary enzyme for its processes. However, for our body to supply all the enzymes entirely by itself would be very taxing. We have to preserve our body's enzyme level. We can replenish our enzyme level by taking foods containing enzymes. (We can also take enzyme supplements.)

In cooked foods, the enzymes are inactivated. This does not mean all the food we eat should be raw. Some food such as meat and rice have to be cooked for them to be digested. Milk and other perishable foods have to be pasteurized in order to kill the pathogenic microorganisms. Clean fruits and vegetables as well as sprouts and soaked cereals are good sources of enzymes.

Why should we take extra enzymes? As we grow older, our enzyme reserve is depleted. By taking enzyme supplements we can replace the slack. We are able to lessen the stress of the body's enzyme-producing organs.

Conservation of Energy and Energy Supply to the Body

This is also known as the first law of thermodynamics. The energy balance for the body is

$$F = A + UD = G + H + UD$$

where F is the food intake converted to energy

A is the energy assimilated

UD is the undigested food or chemical energy of the feces

G is the chemical energy of growth

H is the heat energy of respiration

The food we eat supplies the energy we need. We always want to raise the energy level of our body. The higher the energy level of our body is, the more efficient our body is. The more efficient our body is, the better we will feel. Eating more does not necessarily mean we will feel better. In fact, because of the body's effort to digest too much food, we may actually feel worse. Apparently, we have to be efficient in supplying energy to our body. Is there a method that will make us feel energized all of the time? Some methods are available. Taking energy drinks (Lipovitan for example) is a method that could be used but with caution. These drinks contain vitamin B complex that helps activate the energy of the cell. They also contain caffeine and other

components. These drinks are recommended to be taken in before and after performing an exhausting task. Taken moderately, they are effective. But taking these energy drinks indiscriminately and with alcoholic drinks and drugs could be fatal. A safer method is taking multivitamin supplements. Another method is ensuring efficient delivery of oxygen to the cells of the body. Proper breathing techniques can help us achieve this. Oxygenated drinks are sold but their effectiveness is questionable.

Feeling better or being energetic may be literally “all in the mind”. Our brain uses 20% of the energy we take. It needs enough glucose and oxygen. A lack of this two compounds results in a feeling of being non-energetic.

Conservation of Momentum

This principle is important in dealing with the different fluids that flow in our body. Examples are the blood that flows through our arteries and veins and the air that we breathe.

The human body consists of trillions cells, which must be provided with oxygen and a method of removing the wastes produced. The blood and the vessels provide the transport system. The lungs supply the oxygen and at the same time dispose of carbon dioxide by-product. The blood carries the oxygen to the tissues and removes the carbon dioxide. The blood then comes in contact with the air in the lungs for the exchange of carbon dioxide and oxygen molecules. The cardiovascular and pulmonary systems closely interact and affect the functioning of each other. The blood and the air must flow in a regular manner. The practical application of momentum transfer principle is that we should avoid any blockage in the channels in our body. Impeded blood flow results in elevated pressure. The heart pumps the blood through the arteries. Normal blood pressure indicates a healthy condition of the body. Blockage in the circulatory system increases the blood pressure that may result in stroke or heart attack. Higher blood viscosity is another cause of the increase in pressure. This condition generally results from eating certain types of food that contain too much cholesterol and bad fats. While cholesterol is an important component of our body, which is transported by the blood, an excess of low density lipoprotein (LDL) known as bad cholesterol causes problems in blood flow. Saturated fats and trans fats are the components of LDL. We should avoid eating foods containing long molecules of saturated fats and trans fats (mostly from hydrogenated oil and overheated vegetable oils). We should increase our level of good cholesterol, the high density lipoprotein (HDL), by taking healthy fats such as coconut oil, olive oil, omega 3, and fats from nuts, among others. They combine with cholesterol to form HDL. A high level of cholesterol and high ratio of LDL to HDL results in a higher viscosity of the blood and can cause the formation of deposits in the blood vessel walls. Stress should also be avoided as it can lead to elevated blood pressure. Smoking cigarettes results in introducing carbon monoxide in the body. The carbon monoxide molecule binds to the red blood cells in lieu of oxygen. In response, the body creates more red blood cells to compensate for the lack of oxygen carriers. This results in a more viscous blood. In general, smokers have higher blood pressure and less efficient oxygen delivery to their body.

Air enters the body through the nose and through the windpipe (trachea). The trachea divides into two passageways (bronchi) leading to the left and right lungs. The bronchus divides and redivides about 15 times, at the end of which are millions of alveoli where oxygen and carbon dioxide exchanges occur. We should avoid any blockage in the air passage as well as causing any swelling of the passageway. We should avoid breathing any foreign substance. In general, we should avoid infection of the respiratory system that may cause blockage in the passageway for air.

Charge Balance of the Human Body

Some atoms or molecules in the body can lose electrons and become unstable. They are called “free radicals.” Free radicals grab electrons from other molecules that in turn become free radicals. Our body produces millions of free radicals every moment of the day. Free radicals cause damage in our body and they have to be neutralized. Some of their effects are:

1. Damage to parts of the cell such as cell membrane and liposome.
2. Oxidation of LDL (bad cholesterol) to cause sticking of plaque or deposits in blood vessels.
3. Damage to DNA. Cell replication can be damaged or halted. This is a cause of cancer.
4. Damage to mitochondria and mitochondrial DNA.

The overproduction of superoxide radicals causes oxygen stress. This induces toxic effects such as inflammation, carcinogenesis, aging, and geriatric disease. Free radicals come from many sources. During cell respiration, energy is produced along with free radicals in the mitochondria. While our body has molecules to neutralize them, some may escape. The immune system uses free radicals to destroy invaders. Many prescription drugs produce free radicals. The ultraviolet rays from sunlight and other radiation can knock off electrons from molecules and produce free radicals. That is why unprotected skin exposed to sunlight can cause skin cancer. Pollutants from industrial activities and internal combustion engines have many free radicals and daily exposure to them is detrimental to our health. Cigarette smoke contains many free radicals that even secondary smoke can cause disease to non-smokers.

The major cause of the aging process is the accumulated damage imposed by free radicals. Aside from the damage to organs, the telomers of the chromosomes are shortened and eventually, cells cannot replicate. As mentioned earlier, the metabolism in the mitochondria produces millions of superoxide radicals. Built in our body are the antioxidants that neutralize free radicals or terminate the chain. Some of these antioxidants are superoxide dismutase (SOD), catalase, and glutathione. SOD quickly acts on superoxide free radicals to form oxygen and hydrogen peroxide. The catalase acts on the hydrogen peroxide to produce oxygen and water. The oxygen and water are reused by the body. Catalase can act only in the watery portion of the cell. In the fatty parts of the cell, the glutathione enzyme acts on the hydrogen peroxide. If our body cannot produce enough of the antioxidant enzymes, then the damage to the cells would continue until they are irreversibly damaged and die. If the peroxides are quenched quickly, our body can repair the cell again. When the rate of cell repair is low and the cell death rate is higher, the condition called aging appears.

As mentioned earlier, taking food with enzymes benefits our body. But the antioxidant enzyme SOD, catalase, and glutathione are manufactured inside our body. To raise their level, we should supply the raw materials for their production such as the amino acids to form the protein. To help assemble the protein, we need vitamin C, B vitamins, and trace amount of some minerals such as copper, zinc, manganese, and iron. If any of the compounds needed are lacking, then the rate of production may not cope with the use. To help our body’s natural antioxidants, we should supply supplementary antioxidants. Some molecules containing polyphenols can donate electrons to free radicals. Some vitamins and enzymes have antioxidative properties. The following act as antioxidants:

1. Vitamin E, vitamin C, and lipoic acid.
2. Trace minerals such as zinc, manganese, copper, sulfur, and selenium.
3. Co-enzyme Q10, melatonin, carotenoids, and bioflavonoids.

The sources of antioxidants are herbs, fruits, vegetables, many foods and dietary supplements. At present a great deal of research on antioxidants is ongoing. Some antioxidants are now parts of multivitamins and mineral supplements.

Conservation of Angular Momentum

This conservation law is manifested in body movement, forces to the body, structural strength of the body, balance and equilibrium, and response to the force of gravity. Here, we are mostly concerned about the muscular and skeletal systems of the body. Engineers design machines and structures with the knowledge of the limits of the strength of materials subjected to action of forces. Factors of safety are incorporated in the determining the allowable design values that will prevent the occurrence of accidents and disasters. In a similar manner, we can apply this engineering knowledge when dealing with the human body.

In performing exercises for the body, we should follow the advice of the professionals concerning the proper procedures that should be followed. Surely, they are in conformance with engineering principles. Excessive weights and forces can adversely affect the muscles and the bones that can lead to injuries. For some people, jogging may result in bone injuries due to periodic forces on the skeletal system. Lifting weights at an improper angle can lead to back pains and damage to the spinal column. Accidents in sports activities likewise can damage both the muscular and skeletal systems. As much as possible, protective gears must be worn to prevent potential injuries from various activities.

Preventive Maintenance

Engineers keep equipment and facilities in sound condition by providing methodical inspection, detection and correction of failures that may occur later before they develop as major defects. This is referred to as preventive maintenance, which includes tests, measurements, adjustments, and parts replacement. The primary goal of preventive maintenance is to avoid or mitigate the consequences of failure of equipment. In the first place, failure is prevented before it actually occurs.. It is designed to preserve and restore equipment reliability by replacing worn components before they actually fail. Preventive maintenance activities include partial or complete overhauls at specified periods, oil changes, lubrication and so on. In addition, workers can record equipment deterioration so they know when to replace or repair worn parts before they cause system failure. The ideal preventive maintenance program would prevent all equipment failure before it occurs.

We can apply preventive maintenance to keep our body working and/or extend its life. The application of the engineering principles discussed above becomes guides to follow.

Owner's Manual

When we buy appliances, instruments, equipment, and related devices, we expect and we always get the owner's manual for the proper operation, maintenance, and care of those things. Engineers are familiar with owner's manual because they are closely similar to some product specifications.

We are born and we grow without any formal "owner's manual". We depend upon the usual care and advice from our parents, the school, medical doctors, etc. In a similar manner, we possess a great computer (our brain) but we do not have the proper procedures on how to use it. But how could everyone be provided with an owner's manual. I believe that it is the duty of the

government to provide them. Through legislation, each person can be provided with the basic manual. At an added cost one can have a more advanced and detailed manual.

Conclusion

We can clearly see the application of conservation laws, particularly that of mass, energy, and charge to the human body. The analogy between engineering equipment and the human body is so striking that we wonder sometimes if we care about our equipment more than our own body. We take for granted the condition of our body, as if it is a maintenance-free piece of hardware. Through proper health education and constant reminders for caring for our body, everybody will be able to live a healthy life.

Numerous studies, reports, and research results concerning health and wellness are available from many sources. Selecting the right ones may be difficult. By using engineering and scientific principles, we may be able to discriminate and choose the appropriate ones, especially those that could be classified under preventive maintenance. For more effective health and wellness consciousness, every person must have an owner's manual, which should be provided by the government.

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