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Original Concept

New Era of Integrated Biomedical Engineering and Medicine: STEM Model of Medicine (STEM^2)
Part 1. Gateway to New Formats of Biomedical Engineering Departments

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ABSTRACT

We are now in an era of integrated Biomedical Engineering and Medicine, resulting in STEM model (or format) of Medicine or STEM2, which can be incorporated into both education and clinical care. This paper is about the new formats of Biomedical Engineering departments, involving Biomedical Engineering in Medicine program, which can enable BME departments to be actively involved with medical schools in R&D, and with hospitals in implementing research developments and medical devices in clinical care.

***Biomedical Engineering is providing the gateway to Translational Medicine, based on** (i) biomedical engineering formulation of physiological and organ systems functions and dysfunctional characterization, (ii) design of medical appliances for accurate medical diagnosis of pathological/dysfunctional organ systems, (iii) biomedical engineering design of 3-d printing of prosthetic limbs and human organs, and (iv) technologically designed surgical procedures.*

***For this purpose,** we are formulating the Biomedical Engineering in Medicine program's Computational Courses in (i) Physiological Physics, such as blood flow in the circulatory system, and electrical properties of an axon, (ii) Organ Systems Engineering, such as cardiac engineering, pulmonary engineering, renal engineering,(iii) Medical Diagnostic Apps, for accurate automated diagnosis based on BME characterization of dysfunctional organ systems, such as the use of cardiac contractility index for cardiomyopathic left ventricle with poor ejection fraction, (iv) Customized Surgical Systems and Procedures, and (v) Customized Precision 3-d printed Limb Prostheses, Human tissues, and Organ Replacements. These courses can be offered for Bachelor's, Master's, and PhD degrees in Biomedical Engineering.*

Particularly in the field of Organ Systems Engineering, the disciplines of Cardiovascular Engineering, Pulmonary Engineering, Neurological Engineering, Renal Engineering, Orthopedic & Spinal Engineering can contribute to the hitherto unmet medical professional role of biomedical engineering, and thereby enable graduates to work in medical departments of hospitals.

***While this article is breaking new grounds** in terms of new academic programs and disciplines, we have also provided many related References of my journal papers and elaborate book chapters, to substantiate and provide examples of the new academic programs and academic disciplines outlined in this paper.*

KEYWORDS: Biomedical Engineering, Translational Medicine, Organ Systems Engineering, Customized Surgical Procedures, Customized 3-d printing of Limb Prostheses

§NEW ERA OF BIOMEDICAL ENGINEERING DEPARTMENTS: BME IN PHYSIOLOGY, MEDICINE, AND SURGERY

I. NEW ERA OF BIOMEDICAL ENGINEERING DEPARTMENTS:

Traditionally, Biomedical Engineering (BME) Departments have been offering courses in subjects like Biomechanics, Bioelectrical Engineering, Biochemical Engineering, Biocontrol Systems, Medical Instrumentation, Medical Signal and Image Processing. With this background, BME graduates can work in hospitals' medical technology and equipment departments, as clinical engineers to manage operations, analyze and improve utilization and safety, and support servicing medical equipment and healthcare technology.

However so far, this type of coursework has not fulfilled the "medical professional role of biomedical engineering", which is to enable biomedical engineers to work in hospitals' medical departments (such as Cardiology, Neurology, Orthopedics, and others), to keep developing more quantitative formats of medical disciplines. In this way, Biomedical Engineering can help to further develop these medical fields to become more quantitative and technological, and thereby advance clinical medicine.

We are now entering a new era of (i) Biomedical Engineering in Precision Medicine and Surgery, (ii) Bioengineering based Medical Education, (iii) Mathematical, Scientific, and Engineering based formulations of Medical and Clinical Sciences, leading to scientific and technological formulations of medical and surgical procedures, towards more precision and computational medicine and surgery.

This will entail structuring of MD-PhD (Biomedical Engineering) Program and even MD-PhD (Medical & Surgical Engineering) Program, to train competent (i) medical specialists in precision medical diagnostic and treatment procedures, and (ii) surgical specialists in patient-specific and computationally designed surgical procedures, to thereby enhance the level of specialized clinical care.

Biomedical Engineering is hence trending to serve as a gateway to Translational Medicine, for this new emerging scenario of (i) biomedical engineering formulation of physiological and organ systems functions, and BME characterization of pathological dysfunctional organ systems, such as of heart failure and kidney failure, (ii) medical signal and image processing appliances for accurate medical diagnosis, based on artificial intelligence, (iii) biomedical engineering design of 3-d printing of prosthetic limbs and human organs, (iv) biomedical engineering based precision medical diagnostics (such as of coronary artery stenosis) and surgical procedures (such as of coronary bypass surgery), and even (v) biomedical engineering based medical education curriculum.

II. TRADITIONAL BIOMEDICAL ENGINEERING COURSES:

Traditionally, Biomedical Engineering Departments have been offering the following set of Courses:

(I) Quantitative Physiology I (Cells and Molecules), Quantitative Physiology II (Organ Systems).

(ii) Biomaterials, Cellular and Tissue Biomechanics, Biofluid Mechanics, Biotransport processes, Musculoskeletal Biomechanics.

(iii) Bioelectrical Processes, Physiological Control Systems, Tissue Engineering and Regenerative Medicine.

(iv) Physiological Signals and Processing, Medical Image Processing and Pattern Recognition, Medical Instrumentation.

(v) Pharmaceutical Engineering: Drug designing, producing and delivery systems.

Now, we want Biomedical Engineering Departments to have a medical professional outlook, by educating students to work in the medical and surgical departments of hospitals. For this purpose, we have formatted the Program in Biomedical Engineering in Medicine.

III. BIOMEDICAL ENGINEERING IN MEDICINE PROGRAM

We now recommend that for biomedical engineering to become a medical professional field, the Biomedical Engineering Departments develop this Biomedical Engineering in Medicine Program, to offer Master's and Doctoral Programs and courses in the following domains:

1. Physiological Physics

Physics formulations of Physiological Systems functions and dysfunctions can enable us to clearly explain and depict the physiological systems' functional mechanisms, and then apply them in developing medical diagnostic and monitoring systems. For example, for Cardiovascular Physiology we can study viscous laminar flow in a tube, and how blood pressure is measured by using sphygmomanometer. The study of Electrical field can enable us to determine the electrical field in a cell membrane and the potential difference across the membrane. Then for Neurophysiology, the physics formulation of the concepts of electrical potential, current, resistance and capacitance can be applied to the phenomenon of nerve conduction, by enabling us to analyze the resting potential of axon membrane, the action potential from stimulus, and propagation of the action potential in a nerve axon. (References 43-47).

2. Organ Systems Engineering:

Biomedical Engineering formulation of Organ Systems, such as the Heart, Lungs, Kidneys, Brain, involves (i) analyses of their function, (ii) detection of abnormal function by formulation of indices, (such as non-invasive left ventricle contractility index in terms of pressure-normalized LV systolic wall stress to assess heart dysfunction due to cardiomyopathy, and non-invasive lung ventilatory index to detect lung diseases), and (iii) design of systems and devices to compensate for dysfunction (as for example, ventricular assist device to assist the weakened-contractile left ventricle in providing adequate cardiac output).

In this program, we can offer courses in Orthopedic & Spinal Engineering, Cardiovascular Engineering, Pulmonary Engineering, Pancreatic-Diabetic Engineering, Renal Engineering, Neurological Engineering, Gastrointestinal Engineering. Here are the descriptions of some of these courses, along with references to my journal papers and book chapters.

Orthopedic & Spinal Engineering involves (i) mechanics of function of skeletal and spinal structures, (ii) back pain mechanism and treatment, (iii) scoliosis surgical correction, (iv) design of surgical procedures for joints dysfunction, (v) design of bone fracture fixation plates, (vi) intrinsically optimal design of spinal vertebral body and disc, and (vii) surgical management of fractured vertebral body and herniated spinal disc. (References 1-6, 10-13, 18, 23, 32-33).

Cardiovascular Engineering involves engineering analysis of (i) heart function, left-ventricular contraction mechanism, and intra-ventricular flow formulation, (ii) non-invasive cardiac contractility index for heart failure, (iii) aortic blood flow and determination of aortic pressure profile, (iv) coronary blood flow and cardiac perfusion, (v) customized design of coronary bypass surgical procedure. (References 8, 14, 17, 19, 20, 22, 25-29).

Respiratory-Pulmonary Engineering involves (i) lung ventilation modelling and formulation of ventilatory index for lung disease detection, (ii) respiratory control mechanism, (iii) analysis of gas transfer between lung alveoli and pulmonary capillaries, and formulation of gas transfer index for clinical usage, (iv) basis of weaning of COPD patients. (References 15, 16, 30, 35, 37).

Pancreatic-Diabetic Engineering involves (i) pancreatic regulatory physiology and medical assessment, (ii) glucose-insulin regulatory control system, (iii) glucose tolerance test modeling and patient simulation for glucose and insulin responses, for accurate diabetes detection, (iv) automated insulin infusion regulatory system, for lowering blood glucose after a meal. (v) diabetes technology for optimizing diabetes management: continuous glucose monitoring systems, smart insulin pens, insulin pumps. (References 7, 9, 24, 31).

Renal Engineering involves (i) analysis of the renal system for filtration and regulation of urine concentration, as well as renal clearance of unwanted metabolic substrates, such as creatine, (ii) renal physiology modeling of acid base balance and body fluid balance, (iii) formulation of measurement of creatinine concentration and glomerular filtration rate, (iv) mechanisms of hemodialysis and peritoneal dialysis for kidney failure. (Reference 36).

3. Medical Diagnostic Apps For Automated Medical Signal & Image Processing In Medical Diagnostics:

Over the years, there has been significant number of works and publications on medical signal and image processing methods and techniques for making medical diagnosis. We now need to convert them into devices that can automate accurate medical diagnostics. This will involve courses in design of Medical Diagnostic Apps combining these signal and image processing software into smart apps by using machine-learning and computer-generated artificial intelligence technique, for automatically classifying patterns in data to crowd-source and build on the best medical knowledge from physicians across many countries. Our goal is to provide timely and affordable specialist advice to general practitioners serving millions of people worldwide, in the "safety net" hospitals and clinics. Then, learning of these Medical Apps during Clerkships and Medical Rotations can help to improve the training and performance of primary care physicians.

4. Customized Surgical Systems And Procedures:

This category includes (i) Pre-surgical Patient-specific Surgical Design, and (ii) Creating 3D Surgical Models from Patient Scans.

For obtaining more reliable surgical outcomes, it is necessary to pre-surgically design patient-specific procedures. For example, to obtain the best outcome from coronary bypass surgery on a patient, we need to determine the optimal configuration of distal anastomosis of the graft and the occluded artery, to obtain the ideal blood flow distribution in this anastomotic space which will promote long-term patency of the surgical procedure. (References 25 & 42)

Then for Surgical Precision, surgeons can learn how to (i) guide surgical instruments to the exact place, (ii) move organs out of the way without causing damage, (iii) clamp blood vessels to stop bleeding, (iv) resect (cut out damaged tissue) and remove tumors.

5. Customized Precision 3-d Printed Limb Prostheses, Human Tissues, And Organ Replacements:

The medical industry is now utilizing the rapidly advancing 3D printing technology for human health benefit in a big way. We can now print anything from 3-d printed customized prosthetic limbs to heart valves and dentures, to human organs and human tissues with blood vessels. For a 3D printer to work, we have to feed it instructions in the form of a 3D model, which is a 2-d computer-aided design file designed by using special 3D production software, to create an accurate 3D representation of an object's surface area. The 3D medical printers for artificial tissue use biodegradable materials along with hydrogels comprising of real human cells, which gives the tissue both strength and structure.

6. Scope Of Biomedical Engineering:

These programs can cultivate a new 21stcentury era in biomedical engineering education integrated with medical education, to develop precision medicine and customized surgery in clinical care.

IV. TEXTBOOKS FOR THIS BIOMEDICAL ENGINEERING IN MEDICINE PROGRAM:

This "Biomedical Engineering in Medicine" program will need textbooks. As of now, it can be supported by some of my recent Textbooks:

1. Applied Biomedical Engineering (CRC Press, Taylor and Francis, 2009):

This book uses a problem-based approach to quantify physiological processes, formulate diagnostic and interventional procedures, develop orthopedic surgical procedures; Features: Incorporates material from solid mechanics, fluid mechanics, dynamics and vibrations, control systems, and mathematical Modeling; Provides biomechanical guidelines for internal fixation of bone and spinal fractures as well as the treatment of herniated discs; Presents the mechanics of heart function, heart structures, noninvasive determination of aortic pressure, and characterization of left-ventricular afterload; Discusses detection of infarcted myocardial segments; Assesses the constitutive properties and degeneration of heart valves; Covers the modeling of lung ventilation, its application to lung disease diagnosis, lung gas-transfer mechanism, and indices to assess its performance; Examines how human anatomical structures and physiological processes are designed for optimal functionality. . https://drive.google.com/open?id=0BzOPlHbjWLYta3djeFV0MkRaMXc

2. Biomedical Science, Engineering and Technology (InTech Publishers, 2012):

This book cohesively integrates biomedical science (disease pathways, models and treatment mechanisms), biomaterials and implants, biomedical engineering, biotechnology, physiological engineering, and hospital management science and technology. Together, these topics are providing a pathway for incorporation of STEM into medical knowhow, procedures, and devices, towards a higher order of translational medicine applied in tertiary patient care. Biomedical Science, Engineering and Technology, by Dhanjoo N. Ghista

Chapter 1: Biomedical Engineering Professional Trail from Anatomy and Physiology to Medicine and Into Hospital Administration: Towards Higher-Order of Translational Medicine and Patient Care.

Chapter 35. Physiological Nondimensional Indices in Medical Assessment: For Quantifying Physiological Systems and Analysing Medical Tests Data

3. Cardiology Science and Technology (CRC Press, Taylor and Francis, 2016)

Section 1: Left Ventricular Wall Stress, Contractility and Vector Cardiogram, with Applications in Cardiology:

Left ventricular Wall Stress Compendium; Assessment of Cardiac Function in Filling and Systolic Ejection Phases; Novel Cardiac Contractility Index dσ*/dt (max); Cardiomyopathy effect on Left ventricle (Shape, Wall stress and Contractility) and Improvement after Surgical Ventricular Restoration; Cardiac Contractility Measures for Left Ventricular Systolic Functional Assessment in Normal and Diseased Hearts; Analysis for Left Ventricular Pressure Increase during LV Isovolumic Contraction Phase, due to Activation of the Myocardial Fibers: Computation of LV Myocardial Wall Stresses, Myocardial Fiber Stresses and Orientation; Myocardial Infarct Induced Left Ventricular Shape Remodeling, and Surgical Ventricular Restoration to restore LV Shape and Cardiac Contractility; Vector Cardiogram Theory and Clinical Application.

Section II: ECG Signal Analysis and Cardiac Pumping (Intra-Ventricular, Aortic and Coronary Flow), with Applications in Cardiology and Cardiac Surgery:

ECG and Heart Rate Variability Signal Processing and Analysis to detect Cardiac Arrhythmias; Left Ventricular Blood Pump Analysis and Outcome: Intra-LV Flow and Pressure Distributions to determine Candidacy for Coronary Doppler Echo Velocity Flow Mapping of Normal subjects and Heart Failure Patients; CoronaryBlood Flow Analysis and Coronary Artery Bypass Graft Flow and Design; Coupled Sequential Anastomotic Bypass Graft (SABG) Design of Coronary Bypass Surgery; Cardiac Perfusion Analysis and Quantification by Nuclear Cardiac Imaging and Computation of Intra-Myocardial Blood Flow Velocity and Pressure Patterns; Determination of Arterial Pulse Wave Propagation Velocity and Arterial Properties; Blood Flow in Patient-Specific Coronary Arteries: Causes of Atheromas at Arterial Curvatures and Bifurcations based on Hemodynamic Parameters; Intra-Left Ventricular Diastolic and Systolic Flow Distributions, based on Colour.

[https://drive.google.com/open?id=0BzOPlHbjWLYtR0ZieEFQNTNmVGM]

4. Computational and Mathematical Methods in Cardiovascular Physiology (World Scientific, 2018):

This book has literally transformed Cardiovascular Physiology into a STEM discipline, involving (i) quantitative formulations of heart anatomy and physiology, (ii) technologies for imaging the heart and blood vessels, (iii) fluid mechanics and computational analysis of blood flow in the heart, aorta and coronary arteries, (iv) design of heart valves, percutaneous valve stents, and ventricular assist devices. This book is providing a gateway for this new emerging scenario of (i) science and engineering based medical educational curriculum, and (ii) technologically oriented medical and surgical procedures. As such, this book can be usefully employed as a textbook for courses in (i) cardiovascular physiology in both the schools of engineering and medicine of universities, as well as (ii) cardiovascular engineering in biomedical engineering departments world-wide. [https://www.worldscientific.com/worldscibooks/10.1142/10996].

5. Biomedical Engineering Modeling of Pancreatic, Respiratory, and Renal Systems, and their Medical Assessments

I have finished preparing this to-be-published book by Elsevier Publisher, which can also serve as a textbook for this "Biomedical Engineering in Medicine" program.

V. INVOLVEMENTS OF BIOMEDICAL ENGINEERING DEPARTMENTS WITH MEDICAL COLLEGES

Based on the new era concept of Integrated Biomedical Engineering and Medicine (STEM2), the modern Biomedical Engineering Departments will collaborate with Medical Colleges to offer MD-PhD (Biomedical Engineering) Program and MD-PhD (Medical & Surgical Engineering) Program. In fact, going forward, it will become the norm for biomedical engineering students to also take on this advanced degree.

The PhD components of both these dual-degree programs will involve offering courses, as described in Section III, in Physiological Physics and Organ Systems Engineering. In other words, after completing the basic MBBS (or MD) Degree in four years, the biomedical engineering students will then do PhD. They will take these advanced courses and then do PhD thesis, to become new era scientific-technological physicians and surgeons in medical and surgical specialties.

VI. CONCLUSION

While the field of Biomedical Engineering was formulated in 1960(s), today most biomedical engineering departments work independently of medical schools and even of hospitals. However, the professional arena of biomedical engineering is the hospital setting, by which new research formats in medical and surgical engineering can be incorporated in clinical care.

So, to address this need, in this paper we have proposed and outlined a new set of courses in (i) Physiological Physics and Organ Systems Engineering, as well as (ii) Customized Surgical Systems, and Customized 3-d printing of Limb Prostheses & Organs Replacements. This can enable Biomedical Engineering Departments to closely work with medical schools in Education and R&D, as well as with hospitals by incorporating their research into clinical care.

For that purpose, BME master's degree students can be required to do short-term internships in hospitals. These BME master's degree graduates can then even apply to the new era medical colleges, to do MD-PhD (Biomedical Engineering) which is the new trend in medicine.

Indeed, the STEM future of medicine will be developed by the biomedical engineering departments and their PhD students.

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