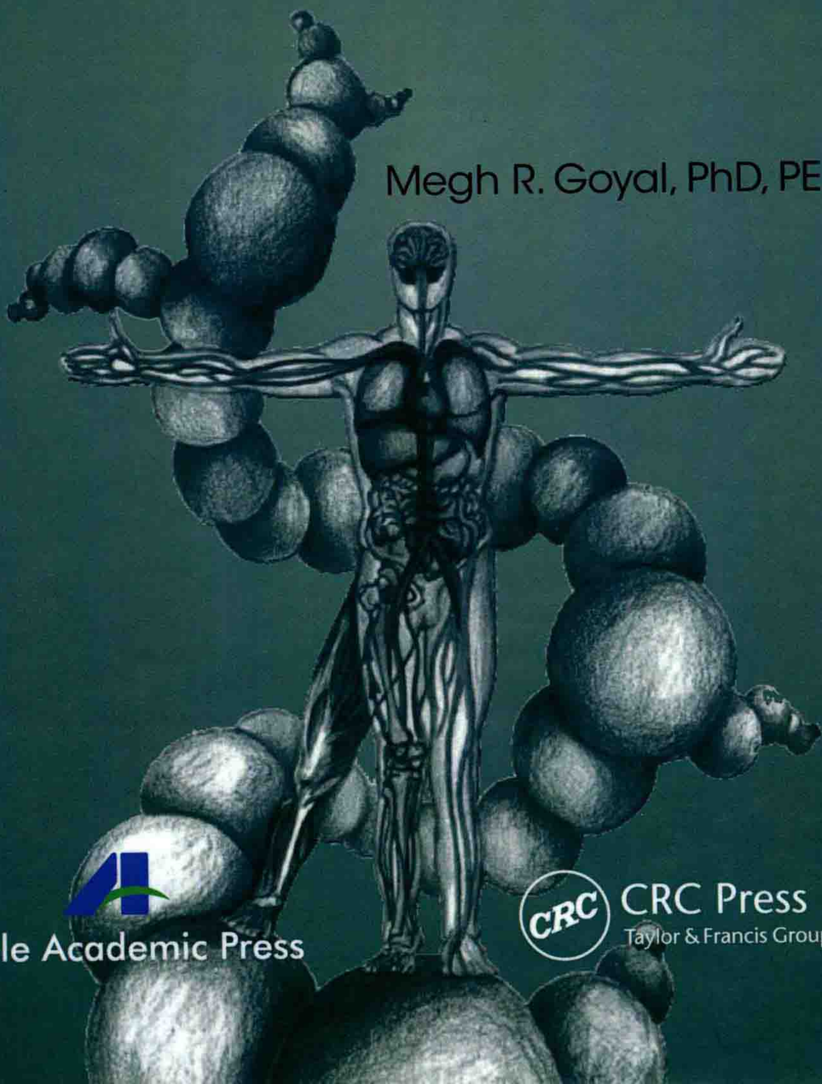
BIOFLUID DYNAMICS of HUMAN BODY SYSTEMS

Megh R. Goyal, PhD, PE



Apple Academic Press

CRC Press
Taylor & Francis Group

BIOFLUID DYNAMICS OF HUMAN BODY SYSTEMS

Megh R. Goyal, PhD, PE

Apple Academic Press
TORONTO NEW JERSEY

Apple Academic Press Inc.
3333 Mistwell Crescent
Oakville, ON L6L 0A2
Canada

Apple Academic Press Inc.
9 Spinnaker Way
Waretown, NJ 08758
USA

Printed in the United States of America on acid-free paper

International Standard Book Number-13: 978-1-926895-46-8 (Hardcover)

Library of Congress Control Number: 2013945096

Library and Archives Canada Cataloguing in Publication

Goyal, Megh Raj, author
Biofluid dynamics of human body systems/Megh R. Goyal, PhD., P.E.
(Advances in bioengineering research and applications book series; volume 1)

Includes bibliographical references and index.
ISBN 978-1-926895-46-8
1. Body fluid flow. 2. Fluid mechanics. 3. Biomechanics. I. Title.
II. Series: Advances in bioengineering research and applications book series; v. 1

QP90.5.G69 2013 612'.01522 C2013-904895-2

Apple Academic Press also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic format. For information about Apple Academic Press products, visit our website at **www.appleacademicpress.com** and the CRC Press website at **www.crcpress.com**

BIOFLUID DYNAMICS OF HUMAN BODY SYSTEMS

ABBREVIATIONS

AIDS	acquired immunodeficiency syndrome
AFI	amniotic fluid index
CFD	computational fluid dynamics
CO	cardiac output
C	Celsius
CNS	central nervous system
CVP	central venous pressure
CBF	cerebral blood flow
CBV	cerebral blood volume
CMRO2	cerebral metabolic rate of oxygen
CPP	cerebral perfusion pressure
CFS	cerebrospinal fluid
CSF	cerebrospinal fluid
CCA	common carotid artery
CT	computerized tomography
DV	daily value
Pdias	diastolic pressure
DRE	digital rectal exam
DB	direct bilirubin
EEG	electroencephalogram
ERCP	endoscopic retrograde cholangio pancreatography
ETEC	enterotoxigenic *Escherichia coli*
ELISA	enzyme linked immuno sorbent assay
EGD	esophagogastroduodenoscopy
ERT	estrogen replacement therapy
ECA	external carotid artery
ECF	extracellular fluid
ESWL	extracorporeal shock wave lithotripsy
F	Fahrenheit
FIU	Florida International University, Miami
FDA	Food and Drug Administration, U.S.A.
Fr	Froude number
GERD	gastroesophageal reflux disease
GI	gastrointestinal
GTP	glutamyl transpeptidase
IMO	implantable membrane oxygenator
IB	indirect bilirubin
IBD	inflammatory bowel disease
ICA	internal carotid artery

IC	interstitial cystitis
ICC	intracranial connections
ICP	intracranial pressure
IVP	intravenous pyelogram
JAM	junctional adhesion molecules
LA	latex agglutination
MRI	magnetic resonance imaging
MAP	mean arterial pressure
MCH	mean corpuscular hemoglobin
MCHC	mean corpuscular hemoglobin concentration
MCV	mean corpuscular volume
PMC	pleural mesothelial cells
PKD	polycystic kidney disease
PCR	polymerase chain reaction
PMN	polymorphonucleocyte
PET	position emission tomography
PE	premature ejaculation
C_p	pressure coefficient
PSA	prostate-specific antigen
ROS	reactive oxygen species
RDI	recommended daily intake
RBC	red blood cells
RDI	reference daily intake
Re	Reynolds number
SBS	shaken baby syndrome
SIDS	sudden infant death syndrome
BSA	body surface area of a person
SVR	systemic vascular resistance
Psys	systolic pressure
TBW	total body water
TENS	transcutaneous electrical nerve stimulation
TUIP	transurethral incision of the prostate
TULIP	transurethral laser incision prostate
TURP	transurethral resection of the prostate
UPR	University of Puerto Rico
UPRM	University of Puerto Rico-Mayagüez Campus
UTI	urinary tract infection
VUR	vesico ureteral reflux
WBC	white blood cells
α	Womersly number

PREFACE

I have been teaching fluid mechanics to undergraduate and graduate students since 1971. I decided to apply principles of fluid mechanics to human body systems when my respiratory system collapsed in 1989 and I had three strokes in 2002 and my vagus nerve failed in 1999. I thought why this would happen to a human body, and I found out that a river of life flows inside my body and the fluids give life to human body systems. This "River of Life" carries different kinds of fluids to give life to all cellular organisms of the body. Also our professional life is similar to a river. Let us all keep our spirits high so that the River of Life will always be dynamic. This is how the idea for this book was born.

Fluid mechanics is a branch of engineering mechanics that deals with response of liquids and gases at rest or in motion. Biofluid mechanics deals with living organisms: agricultural plants, animals, and humans. In this book, I will consider only human body systems. One is interested in variation of velocity, pressure, density, volume, momentum, heat, mass, nutrient or other parameter throughout the biofluid. In the human body, I will consider only continuous fluids (i.e., there is no discontinuity at any point). Biofluid mechanics and computational fluid dynamics (CFD) is one of the specialty areas of biomedical engineering. Biofluid mechanics applies classical mechanics (fluids at rest or in motion, thermodynamics, and continuum mechanics) to biological or medical problems. It includes the study of motion flow within our body and in medical devices and the transport of chemical constituents across biological and synthetic media and membranes. Progress in biofluid mechanics has led to the development of the artificial heart and heart valves, stents, as well as a better understanding of the function of the heart and lung, blood vessels, and capillaries. Medical imaging combines knowledge of a unique physical phenomenon (sound, radiation, magnetism, etc.) with high-speed electronic data processing, analysis, and display to generate an image and study motion of the fluids in our body.

The mission of this compendium is to serve as a textbook or a reference manual for graduate and undergraduate students of biomedical engineering, biotechnology, nanotechnology, nursing, and medicine and health sciences. I hope that it will be a valuable reference for professionals who work with medicine and health sciences, for nursing institutes, and other agencies that work with human health.

There are two books on biofluid dynamics: (1) *Biofluid Dynamics: Principles and Selected Applications*, published: April 26, 2006 by CRC Press: "The book has two main parts: theory, comprising the first two chapters; and applications, constituting the remainder of the book. Specifically, the author reviews the fundamentals of physical and related biological transport phenomena, such as mass, momentum, and heat transfer in biomedical systems, and highlights complementary topics such as two-phase flow, biomechanics, and fluid-structure interaction. (2) *Biofluid Mechanics: The Human Circulation*, 2nd Edition. 2012 by CRC Press, Krishnan B. Chandran, Stanley

E. Rittgers, Ajit P. Yoganathan: "The contents are: PART-I: Fluid and Solid Mechanics and Cardiovascular Physiology: Fundamentals of Fluid Mechanics; Introduction to Solid Mechanics; Cardiovascular Physiology. PART-II: Biomechanics of the Human Circulation; Rheology of Blood and Vascular Mechanics; Static and Steady Flow Models; Unsteady Flow and Non-uniform Geometric Models; Native Heart Valves. PART-III: Cardiovascular Implants, Biomechanical Measurements, and Computational Simulations: Prosthetic Heart Valve Dynamics; Vascular Therapeutic Techniques; Fluid Dynamic Measurement Techniques; Computational Fluid Dynamic Analysis of the Human Circulation; Index." I have thoroughly read the book by Krishnan B. Chandran, et al.

My book complements these books and is unique because it is a complete, simple, one-stop manual on fluid mechanics of human body systems. It includes basic principles and applications, types and mechanics, and flow dynamics through human body systems. It offers basic principles/knowledge/ techniques of fluid mechanics of the human body that are necessary to understand before designing/developing and evaluating a medical device. This book is a must for physicians, scientists, educators, and students.

This book, *Biofluid Dynamics of Human Body Systems*, consists of twelve chapters that include information on physical and chemical properties of fluids in the human body; dimensional analysis; bioheat transfer in the human body; biomass transfer in the human body; biofluid dynamics of human body systems, circulatory, respiratory, brain, urinary, digestive, maternal fetal systems; kinetics of drug delivery in the human body; and instrumentation and measurements of human body fluids. It also contains a glossary of terms and a subject index. Each chapter includes an introduction, body of the chapter, conclusions, summary, keywords, and a bibliography. The chapters in this book are based on my research and teaching materials and special projects by my students in the course on fluid mechanics at University of Puerto Rico-Mayaguez Campus and Florida International University.

The contributions by my students at University of Puerto Rico-Mayaguez and Florida International University has been most valuable in the compilation of this compendium. Their names are mentioned in each chapter. In July of 2001, students of my course on INGE4015 Fluid Mechanics conducted a first congress on "biofluid dynamics of human body systems." The purpose of this congress was to show and learn how the biofluids of the many body systems function and help to maintain a great physical state. In this congress, student groups discussed biofluid dynamics of brain system; ear/throat/nose system; circulatory system; reproductive system; digestive system; respiratory system; urinary system; arthritis; instrumentation and measurements for the human body; challenges in biofluid dynamics of human body systems. In July of 2002, students conducted a second congress on "biofluid dynamics and engineering of artificial organs." The purpose of this congress was to learn biofluid dynamics of bioheat transfer in a human body, biomass transfer in a human body, biofluid mechanics of artificial heart, biofluid mechanics of artificial lung, and biofluid mechanics of artificial kidneys. In April of 2003, students of my course on BME4999 human body systems conducted a third congress on "biofluid dynamics of human body systems" to discuss circulatory system; artificial heart; cardiovascular bypass surgery; respiratory system; kinetics of drug transport; digestive system; maternal fetal system; stenting of intracranial arteries as endovascular bypass of berry aneurysms (Baruch Barry Lieber, PhD, PE, University of Miami). In July of 2004, we conducted a fourth congress on "biofluid dynamics of human body systems" to discuss our body fluids; properties of body fluids; ear/nose and throat system; balloning and stenting; urinary system; artificial kidney; advances in human body fluids; dimensional analysis; biomass transfer; body pain; instrumentation and measurements. It has been an excellent learning experience for me. I thank all of them at University of Puerto Rico-Mayagüez and at Florida International University who have enriched my knowledge in biomedical engineering.

This book would not have been written without the valuable cooperation of a group of engineers and physicians. At the University of Puerto Rico-Mayagüez Campus (UPRM) and Florida International University (FIU), I am grateful to my colleagues: Marco A. Arocha, Jaime E. Ramirez Virk, Ruben E. Diaz, Jayanta Banerjee, Paul Sundaram, Vijay K. Goyal, Ricky Valetin, Ismael Pagan Trinidad, Carlos Rinaldi Ramos, David Suleiman Rosado, Madeline Torres Lugo Eduardo Juan, Alejandro Acevedo, Ramón Vásquez Espinosa, and Ivette Ríos Lamberty.

I owe special gratitude to Anthony McGoron at FIU and Richard Schoephoerster, Dean of the College of Engineering at the University of Texas at El Paso, who taught me to love biomedical engineering during my sabbatical leave at FIU. At FIU, Dr. Richard T. Schoephoerster focused on the role of mechanics in cardiovascular disease development; development of novel cardiovascular devices; determination of the role of fluid mechanics on thrombosis; and application of CFD in the design of heart valves. Dr. James E. Moore Jr. was involved with the mechanics of the cardiovascular system and the interaction with the biological tissues, which make up the arterial wall. The primary focus of Dr. Anthony McGoron is on drug delivery and drug transport mechanisms and modeling, since 1999. He also collaborates with medical scientists at the University of Miami School of Medicine to measure cerebral glucose metabolism (using PET) and cerebral blood flow (using SPECT). I had the opportunity to work closely with all of them including other faculty members. I also thank the executive officers at UPRM Campus to initiate research in biomedical engineering and nanotechnology. The contribution by Dr. C. David Kreger in chapter 3 is greatly appreciated.

I would like to thank editorial staff, Sandy Jones Sickels, Vice President, and Ashish Kumar, Publisher and President, at Apple Academic Press, Inc. (http://appleacademicpress.com) for making every effort to publish the book when the human health is a major issue worldwide. Special thanks are due to the AAP production staff. I request the reader to offer me your constructive suggestions that may help to improve the next edition. The reader can order a copy of this book for the library, the institute or gift from CRC Press [Taylor & Francis Group] 6000 Broken Sound Parkway NW Suite 300, Boca Raton, FL 33487 – USA; telephone at 800-272-7737 < http://www.crcpress.com/product/isbn/9781926895468>.

Finally, a river of thanks flows from my heart and soul to my wife, Subhadra D Goyal, for the understanding and collaboration of sharing the responsibility, time, and devotion necessary to prepare this book. With my whole heart and best affection, I dedicate this book to Luis C Gonzalez, Neena Devi Gonzalez, and Nicole Grace Gonzalez. They always motivate me to live longer and to live happier to serve the world community. I also dedicate this book to "those who want to live happily." Good health brings happiness to one and all.

–Megh R. Goyal, PhD, PE
June 1, 2013

FOREWORD

In my physics class, I was taught that a fluid is a substance that continually deforms under an applied shear stress. Fluids are a subset of the phases of matter and include liquids, gases, and plasmas. In medicine, "fluid" is often used as a synonym for "liquid," with no implication that gas could also be present. The colloquial usage of this term is common in medicine and in nutrition ("take plenty of fluids" or "drink 8 glasses of water every day for better health"). Liquids form a free surface while gases do not. The distinction between solids and fluid is made by evaluating the viscosity of the substance.

A biofluid is a biological fluid: a liquid made by the body itself (animal, human or agriculture plant). In our body, biofluids can be excreted through sweat, secreted through bile, obtained through a needle when blood is drawn, or they may develop from a blister or cyst. Body water is also a biofluid, as is earwax, amniotic fluid, cerebrospinal fluid, pus, and saliva, among many others. Biofluid is usually a term used by biomedical engineers and those in the medical profession. Most other people simply call them bodily fluids. Biofluid is also a common term used by law enforcement officers when working crime scenes. DNA is contained in many bodily fluids, and the proper, safe handling of it is something that all crime scene workers should be trained in. Analyzing biofluids can be the ultimate key in solving rape and murder cases.

Medical hygiene workers, hospitals, and doctors' offices increasingly treat biofluids as dangerous because they could potentially carry blood borne diseases. Since the onset of AIDS and other diseases, biofluids have been treated with increasingly specialized care. Nurses and doctors have strict rules in how they are acquired, handled, and disposed. Strict biofluids management produces important infection and disease control.

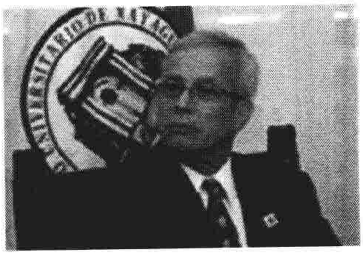
Fluids display properties such as: 1. Not resisting deformation, or resisting it only lightly (viscosity); and 2. The ability to flow (also described as the ability to take on the shape of the container). This also means that all fluids (gases and liquids) have the property of fluidity. These properties are typically a function of their inability to support a shear stress in static equilibrium. Solids can be subjected to shear stresses and to normal stresses—both compressive and tensile. In contrast, ideal fluids can only be subjected to normal stress, which is also called pressure. Real fluids display viscosity and so are capable of being subjected to low levels of shear stress.

The Food and Drug Administration (FDA) and Health Canada have defined "Reference Daily Intake or Recommended Daily Intake (RDI)" as a daily intake level of a nutrient that is considered to be sufficient to meet the requirements of 97–98% of healthy individuals in every demographic in the United States (where it was developed, but has since been used in other places). Water can be considered a nutrient. The RDI is used to determine the Daily Value (DV) of foods, which is printed on nutrition facts labels in the United States and Canada. The amount of water varies with the individual, as it depends on the condition of the subject, the amount of physical exercise, and on the environmental temperature and humidity. In the US, the reference daily intake (RDI) for water is 3.7 for a male older than 18, and 2.7 liters per day for a female older than 18. The RDI includes water contained in food and contained in food, beverages, and drinking water. The common misconception that everyone should drink two liters (68 ounces, or about eight 8-oz glasses) of water per day is not supported by scientific research. For example, people in hotter climates will require greater water intake than those in cooler climates. An individual's thirst provides a better guide for how much water they require rather than a specific, fixed number. A more flexible guideline is that a normal person should urinate 4 times per day, and the urine should be a light yellow color. Water is necessary for all life on Earth. Humans can survive for 4–6 weeks without food, but for only a few days without water. Do we have enough potable water for all persons on our mother planet?

A constant supply is needed to replenish the fluids lost through normal physiological activities: respiration, perspiration, and urination. In terms of mineral nutrients intake, a researcher is not sure how the drinking water contributes to RDI requirements. However, inorganic minerals generally enter surface water and ground water via storm water runoff or through the Earth's crust. Treatment processes also lead to the presence of some minerals. Examples include calcium, zinc, manganese, phosphate, fluoride, and sodium compounds. Water generated from the biochemical metabolism of nutrients provides only a small fraction of a human's necessary intake. There are a variety of trace elements present in virtually all potable water, some of which play a role in metabolism. For example sodium, potassium, and chloride are common chemicals found in small quantities in most waters, and these elements play a role (not necessarily major) in body metabolism. Other elements such as fluoride, while beneficial in low concentrations, can cause dental problems and other issues when present at high levels. Water is essential for the growth and maintenance of our bodies, as it is involved in a number of biological processes. Profuse sweating can increase the need for electrolyte replacement. Water intoxication (hyponatremia) is a process of consuming too much water too quickly and it can be detrimental to human health. The human kidneys will normally adjust to varying levels of water intake. The kidneys will require time to adjust to the new water intake level. This can cause someone who drinks a lot of water to become dehydrated more easily than someone who routinely drinks less.

I am a Soil Scientist. As a President of University of Puerto Rico (UPR), I have contacts with the scientists at UPR School of Medicine and have attended several conferences related to human health. Our health depends on our bodily water. Therefore I can affirm: Movement of fluids with nutrients move to organs of human body is analogous to movement of fluids to all parts of a fruit tree. The tree derives its water needs through flow inside the xylem and evapotranspiration from the tree surface. The consumptive use of a tree depends on the climatic/ soil/ crop factors. Water stress affects performance of a fruit tree and fruit yield. We humans derive our water need by intake of water/juice and food and the process of perspiration from the skin. RDI for water depends on the need of an organ and climatic/ human factors. Water stress in humans (Dehydration) affects human performance/daily life and efficiency.

I am enthusiastic to know that Apple Academic Press Inc. and Dr. Megh R. Goyal (whom I have known since 1979) have put together this compendium on *Biofluid Dynamics of Human Body Systems*. The reading of this book has enriched my knowledge and has convinced me that liquids play a tremendous role in our health. The book is not only simple but also is thorough. The book is very informative and is a complete manual on how human body fluids move to carry necessary nutrients and chemical agents to each cell. Our body is a marvelous living robot that will not survive more than three days without water. Dr. Goyal, master of fluid dynamics, has applied principles of engineering mechanics to human body fluids in with simple and understandable language. I hope that this manual will improve the quality of life.



Miguel A. Muñoz Muñoz, PhD
President of University of Puerto Rico,USA
Professor, Researcher, and Former Chairman of Department
University of Puerto Rico-Mayagüez Campus
CALL Box 9000
Mayagüez, P.R. 00681-9000
Telephone: 787-832-4040 ext. 2313 , 3511, 3859
Fax: 787-265-3884, 265-5490
E-mail: Miguel.munoz3@upr.edu

FOREWORD

I am glad to hear that Prof. Megh R. Goyal has attempted a textbook on *Biofluid Dynamics of Human Body Systems*. I believe this innovative book will not only aid student community but also researchers coming from Asia-Pacific region who are eagerly waiting for such a manual. His vast experience in this area is greatly reflected in the book chapters. Since I belong to the same fraternity, I wish success for both the author and publisher to bring this exciting textbook.

Professor (Dr.) Saravana Kumar Jaganathan
Dean, Research and Former Head
Department of Biomedical Engineering,
PSNA College of Engineering and Technology
Kothandaraman Nagar, Dindugal 624622, Tamil Nadu, India
Phone No: 0451-2554124
Email: deanresearch@psnacet.edu.in

FOREWORD

Megh Raj Goyal, PhD, PE, has chosen to write a textbook on a very important topic in medicine and engineering. *Biofluid Dynamics of Human Body Systems* presents a thorough review of hemodynamics and mechanics as they apply to the more critical components of human physiology, concentrating on the biomedical engineering approaches to understanding and treating disease. The chapter on heat transfer and the chapter on mass transport provide for an even more comprehensive coverage of biotransport processes in our human body. All chapters in this book are from a practical but less complicated and technical perspective.

The book should serve as a text for a course or as a valuable reference with practical applications and values of human physiological processes that will be useful to students, instructors, researchers, and device designers alike. Engineers, scientists, and clinicians should find this book equally valuable.

Biofluid dynamics has a particular importance to drug delivery. For drugs to reach their target, they must cross membranes, undergo convective transport in the circulatory system, distribute in the interstitial fluid of tissues, and enter cells to reach their intended site of action. A clear understanding of biofluid dynamics is critical to the design of efficacious drugs with minimal side effects that result from drugs reaching unintended targets. The blood brain barrier, and other selective barriers, present a particular challenge to drug transport, limiting the development of drugs for neural applications, such as Parkinson's, Alzheimer's, epilepsy, depression, schizophrenia, and brain tumors. Dynamic and static *in vitro* models of the blood brain barrier are used by pharmaceutical companies to screen potential drugs for the brain and are therefore an important model to study drug delivery and for drug development. Cerebral spinal fluid and intracranial pressure also significantly impact drug delivery to the brain and so must be thoroughly understood for optimal drug design. Therefore, a general knowledge of biofluid dynamics is important to many areas of engineering and medicine.

Professor Goyal is uniquely qualified to present these important topics in this book. I learned a great deal during his year-long visit in 2003 to the Biomedical Engineering Department at Florida International University and am proud to have contributed to this book.

Anthony McGoron, PhD
Associate Professor and Undergraduate Program Director
Biomedical Engineering Department
Florida International University
10555 West Flagler Street, EAS 2600
Miami, Florida 33174
Phone: (305) 348-1352
Fax: (305) 348-6954
E-mail: Anthony.mcgoron@fiu.edu

FOREWORD

In 1994, Dr. Megh Raj Goyal taught me courses on soil and water management and farm machinery when I was an undergraduate student at the University of Puerto Rico-Mayagüez Campus. He was one of my favorite professors. After receiving my BSc degree in agriculture sciences, I decided to enter the medical school to become a specialist in internal medicine and respiratory mechanics. After reading and editing this manuscript, I feel honored to write a foreword for this book thus paying tribute to my professor.

I want to share with the readers what I learned from the textbook *Medical Physiology* by Arthur Guyton and other authors. The human body is a fascinating job of our Almighty God. It is made up of a head, neck, torso, two arms and two legs. The human body is made to stand erect, walk on two feet, use the arms to carry and lift, and has opposable thumbs (able to grasp). The adult body is made up of 100 trillion cells, 206 bones, 600 muscles, and 22 internal organs. Every square inch of the human body has about 19 million skin cells. Every hour about 1 billion cells in the human body must be replaced. The average human head has about 100,000 hairs. The arteries, veins and capillaries are about 100,000 kilometers long. The heart beats more than 2.5 billion times in an average lifetime. The human heart creates enough pressure to squirt the blood 30 feet high. It takes about 20 seconds for a red blood cell to circle the whole body.

The human body has nine major systems: circulatory system; respiratory system; musculoskeletal system; nervous system; reproductive system; digestive system; urinary system; lymphatic system; integumentary (dermal) system. Five minor systems include the immune system; excretory system; endocannabinoid system; endocrine system and vestibular sensory system). Each system plays a vital part in the health and well-being of the entire body.

The circulatory system pumps and channels blood to and from the body and lungs with heart, blood, and blood vessels. Blood is a medium that transports oxygen, from the respiratory system to the cells. Blood also transports sugars, chemicals, proteins, hormones, and many other substances around the body for use and elimination. As the heart pumps blood, a pulse beat can be felt at various locations in the body, and each pulse beat corresponds to one heartbeat. The heart rate of the average adult at rest is between 80 to 120 beats per minute, depending on age, medical conditions, and general fitness.

The respiratory system is composed of the airway (mouth, nose, trachea, larynx, bronchi, and bronchioles) and the lungs (including the small air sacs called alveoli). The respiratory system provides oxygen to the blood and takes away the waste product called carbon dioxide. Oxygen is extracted from air inhaled through the airway and goes into the blood stream through the membranes of the lungs. For the first aider, maintaining a casualty's airway is of primary importance.

The musculoskeletal system is composed of muscles that provide movement and a skeleton that provides structural support and protection with bones, cartilage, ligaments, and tendons. Most muscles used for movement work by contracting and relaxing in conjunction with a bone.

The nervous system [the central nervous system and the peripheral nervous system] collects, transfers, and processes information with brain, spinal cord and nerves.

The reproductive system includes the sex organs. This is linked to the body's endocrine system, through the female's ovaries and the male's testes. These are known as the gonads or 'sex glands.' The female reproductive system consists of ovaries (where the fertilized egg is lodged for growth), fallopian tubes, uterus (or womb), vagina, and mammary glands. The male reproductive system is composed of the testes (which produce sperm), the seminal vesicles that provide the fluid medium for the sperm and the penis, and prostate.

The digestive system helps in digestion and processing of food with salivary glands, esophagus, stomach, liver, gallbladder, pancreas, small and large intestines, rectum, and anus. Fluid and solids are passed through the esophagus to the stomach where they are processed for further digestion. They are then absorbed into the body through the membranes of the intestines. Some organs, such as the liver and pancreas, are considered accessories to the digestive system as they help process food into various chemical substances used by the body.

The urinary system (kidneys, ureters, bladder and urethra) is involved in fluid balance, electrolyte balance and excretion of urine. This system flushes waste products suspended in fluid from the body. It plays a vital role in keeping the body healthy. Should the urinary system fail (especially the kidneys), then the affected person requires external assistance to get rid of the waste products by 'flushing' the blood. This is called hemodialysis or dialysis.

The lymphatic system is involved in the transfer of lymph between tissues and the blood stream, the lymph and the nodes and vessels that transport it. The lymphatic system is a slow moving system where toxins such as venom tend to accumulate after a bite has occurred. This system provides lymphatic fluid that drains from the body's tissues, which is important as a 'flushing' mechanism. Most toxins and infections absorbed or injected into the tissues are collected by the lymphatic system and 'strained' through lymph nodes in the armpits, neck and groin. The lymphatic fluid eventually drains into the blood stream.

The integumentary (dermal) system is composed of skin, hair and nails. Their pigmentation (color) and growth are linked to the endocrine system. The skin is the body's largest organ and plays an important role in protecting the body from infections. The other functions of skin include acting as a shield against injury and keeping body fluids in. The skin is made from tough, elastic fibers, which have the ability to stretch without tearing easily.

The immune system fights off disease. It is composed of bone marrow, lymph nodes, leukocytes, tonsils, adenoids, thymus, and spleen (many types of protein, cells, organs, tissues). The excretory system is composed of lungs, large intestine, and kidneys.

The endocannabinoid system includes neuromodulator lipids and receptors involved in a variety of physiological processes including appetite, pain-sensation, mood, motor learning, synaptic plasticity, and memory.