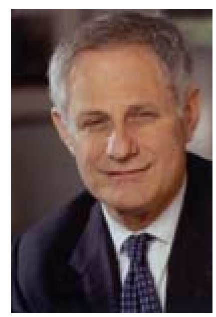
March 2007

Welcome to the Department of Biomedical Engineering at Columbia University

Welcome from Dean Zvi Galil



Welcome to the Department of Biomedical Engineering at The Fu Foundation School of Engineering and Applied Science, one of the most exciting engineering schools in the world! An enduring hallmark of our school is the embracement of new technologies, innovative approaches, and interdisciplinary possibilities. It has been my pleasure to see the birth of Biomedical Engineering as a department in SEAS, a bright example of this tradition and a significant milestone in the history of this school.

Through a synergy of teaching and research, Biomedical Engineering offers strong, broad-based instruction at both undergraduate and graduate levels, seeking to educate the next leaders in technology and applied science. Expanding from a strong, pioneering history in Biomedical Engineering, this young Department offers instruction in a wide range of fields leading to diverse careers in academic, industrial, medical, and currently undiscovered directions. We welcome you to join us on this exciting journey into the future.

March 2007

Welcome from Chair Van C Mow

Welcome to the Department of Biomedical Engineering at Columbia University. Biomedical engineering, or bioengineering, is an exciting new discipline of engineering that applies the rigorous methods of physics, chemistry, mathematics and engineering to solve important biological and biomedical problems. At Columbia, bioengineering studies have been ongoing since 1962, one of the oldest programs in America, steadily building a solid foundation for the new Department. In 1996, Columbia University decided that is was propitious to start a new permanent academic department in the School of Engineering in the belief that this new department will be vital for the University, and the new discipline will be vital for the welfare of the nation in the 21st century. This new Biomedical Engineering Department was established in January 2000. With a top rated medical school and an excellent engineering school, the University provides a fertile environment for biomedical engineers to develop innovative and outstanding opportunities to pursue some of the most important biomedical problems facing our society. In order to develop depth in our program, we have focused our attention on three important avenues of studies: biomechanics (orthopaedics and cardiac), biomedical imaging, and cellular and tissue engineering.

I hope that you will take some time to peruse our brochure. It offers a wealth of information about us, as faculty members, and about our program. I look forward to personally hearing from you as a prospective undergraduate or graduate student, or postdoctoral fellow or even faculty member.

The Department of Biomedical Engineering

In January 2000, the Department of Biomedical Engineering was officially launched. To provide focus and inclusiveness, three primary research and educational tracks were identified for emphasis: 1) tissue engineering, 2) biomechanics and 3) biomedical imaging, with the BME faculty and students equally divided over these three disciplines. The creation of the new department saw the rapid increase in numbers of faculty and students engaged in biomedical engineering. For the previous 36 years, the average level of graduates in biomedical engineering was five out of the total of 180 in SEAS each year. Since January 1996, the number of undergraduate BME majors (combined juniors and seniors) has risen dramatically, from 11 in 1995 to 120 in 2004, a number comprising 1/5 of the total number of the SEAS students from a total of 11 departments. Biomedical Engineering is the third largest SEAS department after the Computer Science and Electrical Engineering departments. At the graduate level, in 1996 there were 10 graduate students in BME while today there are more than 90 M.S. and Ph.D. students with the number and quality of applications also rising dramatically. The increase in the student population and quality has been mirrored by increase in the departmental faculty and support staff as well as physical research and instruction space on both the Morningside Heights and Health Sciences campuses. Currently, there are 15 faculty members with primary appointments in the BME department and more than 30,000 square feet of space on both the Morningside and Medical Campuses.

Columbia's Department of Biomedical Engineering adheres to the working definition of biomedical engineering promulgated by the National Institutes of Health (http://www.becon.nih.gov/bioengineering_definition.htm):

> *Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health. It advances fundamental concepts, creates knowledge from the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health.*

The goal of the BME faculty is to establish academic and research programs of national and international renown, in our traditional areas of strength, as well as in new and exciting areas that will lead to significant advances in basic and clinical biomedical sciences and technologies. Our program focuses on biomechanics, an area of traditional strength at Columbia; biomedical imaging, an area where Columbia has a renowned history; and the exciting areas of cellular and tissue engineering, which burgeoned in the 1990s. These three broadly defined academic tracks provide focus within the broad interdisciplinary field of biomedical imaging, while offering opportunities for fruitful cross-fertilizations and synergies in education and research.

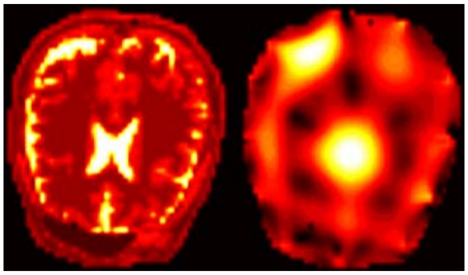
a. Biomechanics

Mechanics is the branch of applied mathematics dealing with motion, and forces producing motion. Biomechanics is the study of the mechanics of living organisms and structures. At Columbia, the DBME faculty's research in biomechanics includes the study of cartilage mechanics in relation to osteoarthritis, bone mechanics in relation to osteoporosis, cardiac mechanics in relation to infarcts and heart failure, and brain mechanics in relation to head injuries and trauma. These research efforts span the range from the cellular level to the tissue and organ levels, and involve sophisticated theoretical, computational and experimental techniques, including animal studies and tools of modern biology.

b. Cellular and Tissue Engineering

Cellular engineering is the branch of cell biology which focuses on mechanotransduction, which is the response of cells to physical stimuli. It subsumes the field of cell biomechanics. In the DBME, research in cellular engineering includes the study of the calcium response of cartilage and bone cells to fluid shear flow, osmotic loading, and electrical fields; the analysis of beating cardiac cells with atomic force microscopy; the study of cell interactions with micro- and nano-scale features of topology, chemistry, and extracellular signals; the biophysics of cell signaling involving biomembrane-associated proteins; study of the nervous system, including the role of the cytoskeleton in injury, the application of genomic and proteomic technologies to mechanotransduction, and repair strategies using stem cells; cell-cell signalling in controlled 2D and 3D microenvironments, and molecular design for controlling cell-material interactions.

Tissue engineering is the use of a combination of cells, engineering or tissue-matrix materials, and suitable biochemical factors to produce tissue substitutes which improve or replace biological and physiological functions. Functional tissue engineering places special emphasis on the engineering of tissue substitutes which can replicate the mechanical function of native tissues. In the DBME, functional tissue engineering research focuses on articular cartilage, bone, ligaments, and cardiac muscle, all of which have demanding mechanical functions. Special emphasis is also placed on the development of tissue interfaces such as ligament-bone and cartilage-bone interfaces which require strong integration, and the use of adult and embryonic stem cells.



c. Biomedical Imaging

Biomedical imaging is the science and the branch of medicine concerned with the development and use of imaging devices and techniques to obtain internal anatomic images and to provide biochemical and physiological analysis of tissues and organs. In the DBME, biomedical imaging focuses on mathematical analysis and quantification of medical images, adaptive signal and image processing, neurocomputational modeling and neuroengineering, pattern recognition, and computer-aided diagnosis; research in magnetic resonance imaging and spectroscopy; Bayesian signal analysis; development and application of new optical imaging technologies, microscopy and spectroscopy; optical imaging of in-vivo function and physiology, cerebral hemodynamics, vascular reactivity, heart, skin, joints, and optical molecular imaging; model-based tomographic image reconstruction algorithms and medical instrument development; ultrasonic imaging and therapy, elasticity imaging.

Programs of Study

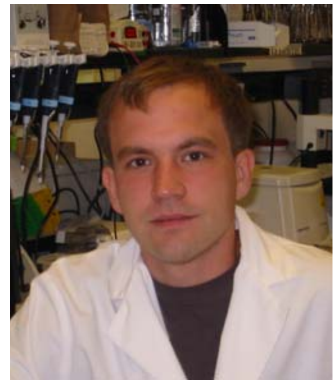
Biomedical engineering is an evolving discipline in engineering that involves collaboration among engineers, physicians, and scientists to provide interdisciplinary insight into medical and biological problems. The field has developed its own knowledge base and principles that are the foundation for the academic programs of Columbia University's Department of Biomedical Engineering. The graduate programs in biomedical engineering (M.S., Eng.Sc.D., Ph.D.) prepare students to apply the principles of engineering and applied science to problems in biology, medicine, to understand the dynamics of living systems, and to develop biomedical systems and devices. Modern engineering encompasses sophisticated approaches to measurement, acquisition, storage, and analysis of data, simulation, and systems identification. These techniques are used in the study of individual cells, tissues, organs, entire organisms, and populations and environments. The increasing value of mathematical models in the analysis of living systems is an important sign of the success of contemporary biomedical engineering activity. The programs offered in the Department of Biomedical Engineering emphasize the confluence of basic engineering science and applied engineering with the physical and biological sciences, with emphasis in the areas of biomechanics, cellular and tissue engineering, and biomedical imaging. This joining of the diverse scientific fields is complemented by strong academic and research collaboration with various other University departments. Graduate courses offered by the Department of Biomedical Engineering are complemented by courses offered by other departments in the Fu Foundation School of Engineering and Applied Science (SEAS) and in the Faculty of Medicine, the School of Dentistry and Oral Surgery, and the Mailman School of Public Health. Master's candidates are expected to complete 30 credits of approved graduate-level course work, including required courses in quantitative physiology and advanced mathematics. Doctoral candidates are expected to complete 30 credits beyond the master's degree, pass an oral and written qualifying examination, and successfully defend their doctoral dissertations, which are based on individual research. In addition, all doctoral students must demonstrate teaching competence as part of their training.

Our Graduates

Janine Boumans

Bone and Orthopaedic Division
Technological University of Eindhoven (TUE**)**
Eindhoven, Netherlands

"My name is Janine Boumans and I am a biomedical engineering student in the Bone and Orthopaedic Division at the Technological University of Eindhoven (TUE) in the Netherlands. In 2005, I did my external internship at the Biomedical Engineering Department of Columbia University in Dr. Mow's lab. I wanted to challenge myself and see what I was capable of doing in research on cartilage (considered to be one of the most difficult biomedical research areas). I was fortunate that Professor Rik Huiskes of TUE offered to arrange for me an internship with Dr. Mow. During this internship I saw a whole other perspective in research, closer collaborations with other students in the lab, weekly meetings with people of the Department and especially the encouragement of everybody to learn more and delve deeper into the subject, and to explore new areas of research that I could be interested in. This was really a wonderful experience for me, and for the first time in my student career I was motivated to think about pursuing a PhD doing human joint research and osteoarthritis. The enthusiasm of my supervisor, Dr. Mow, for the way I was working really encouraged me. So this internship gave me another perspective of myself as a researcher. From this experience, I decided to do joint biomechanics research to study this major disease that affects so many people worldwide."



Robert L. Mauck, PhD

Assistant Professor of Orthopaedic Surgery
Assistant Professor of Bioengineering
McKay Orthopaedic Research Laboratory
University of Pennsylvania
Philadelphia, PA

"My name is Robert Leon Mauck and I graduated from the Department of Biomedical Engineering at the Fu Foundation School of Engineering and Applied Science in 2003, with my dissertation focusing on the functional tissue engineering of articular cartilage. Prior to my doctoral studies, I pursued undergraduate degrees in Biochemistry and Biomedical Engineering at Columbia College and FF SEAS. While in residence at Columbia, I was a founding member of GraBME, a Biomedical Engineering graduate student group. After leaving Columbia, I was a postdoctoral fellow at the National Institutes of Health, in the Cartilage Biology and Orthopaedics Branch of NIAMS (Branch Chief: Dr. Rocky S. Tuan). My current research focuses on the role of physical forces in the chondrogenic differentiation of mesenchymal stem cells, the design of novel bioreactor systems for cartilage tissue engineering, and the production of anisotropic biodegradable nanofibrous matrices for musculoskeletal tissue engineering."

Morakot Likhitpanichkul, PhD

Assistant Professor,
Chiang Mai University
Thailand

"My name is Morakot Likhitpanichkul and I was a PhD student working with Prof. Van C. Mow in the Liu Ping functional tissue engineering laboratory in the department of Biomedical Engineering (DBME) from 2000-

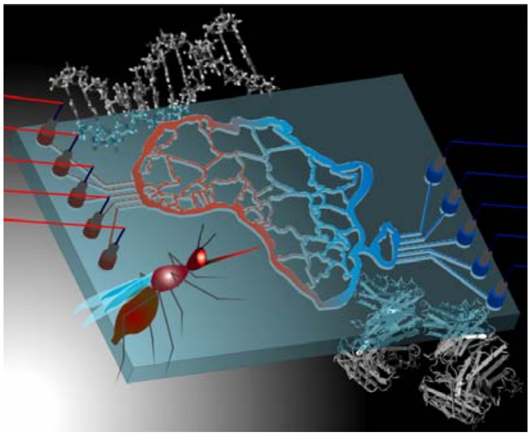
2006. My PhD thesis is titled, “The cell-matrix mechano-electrochemical interactions in articular cartilage: Experiments and triphasic model”. I am originally from Thailand and had a bachelor degree in Mechanical Engineering from Chiang Mai University, Chiangmai, Thailand, before I decided to come to the US for her graduate study. The DBME at Columbia University certainly offers a world-class education in the interdisciplinary field of biomedical engineering. Many of DBME faculty members are international leaders in their fields. The department offers a rich array of programs and opportunities for students to gain valuable knowledge and research experiences. I was particularly interested in the field of Biomechanics and DBME at Columbia undoubtedly is one of the strongest in this field. Furthermore, diversity among classmates, lab-mates and even faculty members in the department provides a friendly and yet motivating study environment for all foreign students. I am currently one of the faculty members in the department of Mechanical Engineering, Chiang Mai University, where I graduated from in Thailand. I continue to conduct biomechanics research and I hope to be an important part of the establishment of biomedical engineering research and education in Thailand.”

Lori Setton, PhD

M. Yoh and H. L. Yoh, Jr. Associate Professor
of Biomedical Engineering
Associate Professor of Surgery
Duke University

“I received my B.S.E. from Princeton University in Mechanical and Aerospace Engineering and my M.S. in Mechanical Engineering from Columbia University. I remained at Columbia and completed my Ph.D. in Mechanical Engineering in1993. I joined the Department of Biomedical Engineering at Duke University in 1994. I now hold positions as Associate Professor in both Biomedical Engineering and the Division of Orthopaedic Surgery in the Department of Surgery. Research in my laboratory is focused on the role of mechanical factors in the degeneration and repair of soft tissues of the musculoskeletal system, including the intervertebral disc, articular cartilage and meniscus. Work in my Laboratory is focused on the development of novel materials for application to tissue regeneration or drug release for the treatment of cartilage disorders. Research in my Laboratory has been funded by the National Institutes of Health, National Science Foundation, The Whitaker Foundation, the Orthopedic Research and Education Foundation, and The North Carolina Biotechnology Center. In 1997, I was awarded the Presidential Early Career Award for Scientists and Engineers (PECASE) from the NSF for my research in determining mechanisms of articular cartilage degeneration. My contributions to research and teaching of graduate students has also been recognized with the Dean's Award for Outstanding Research in 2001 and Excellence in Mentoring, Duke University, received in 2004."

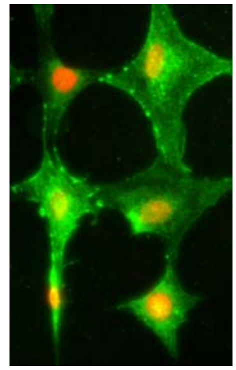
Projects and Centers in BME



Micro- /Nano-technology

Micro- and nano-technology have had immeasurable impact on the field of biomedical engineering, offering new approaches to understanding biological function, enhancing imaging, and providing new tools for design of therapeutic and analytical devices. Biomedical Engineering offers a rich environment for developing these techniques towards a broad range of applications. Current opportunities include understanding bone design, deployment of technology to developing countries, and Nanomedicine. These directions are highly integrated with other departments within the School of Engineering and Applied Sciences, as well as the larger Columbia community.

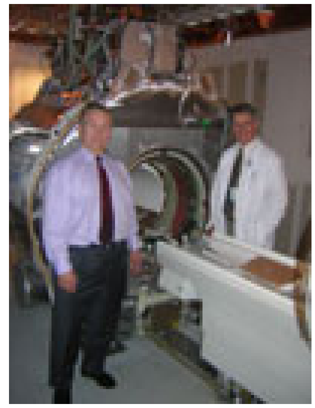
Medical and Dental School collaborations



There are several collaborations between Biomedical Engineering and several departments in the Medical and Dental Schools on the Columbia University Medical Center. In the Medical School, the Magnetic Resonance (MR) Research Laboratories of Columbia University are a research resource for the University consisting of three centers. Located in the basement of the Neurological Institute in a recently renovated 12,000 square foot facility, the three centers are: The Hatch Research Center, the fMRI Research Center and the Biomedical Engineering Imaging Research Center. New equipment and expanded research capabilities include a new 1.5 Tesla full-body MR system (Philips Medical System) for MR imaging research and MR spectroscopy. An upgrade to a 3.0 Tesla magnet is scheduled for installation in 2004. In the fMRI Research Center, a 1.5 Tesla fMRI system (General Electric) has been installed along with state-of-the-art fMRI electronics and computing facilities. These new research laboratories compliment the existing 9.4 Tesla small animal MR Micro-Imaging research system (Bruker) in the Black Building 17th floor and the small animal micro PET research scanner in the Milstein Basement. Together, they provide a broad range of MR imaging resources for Columbia. The Biomedical Engineering Research Center is a facility for the BME Department's Imaging Core with advanced imaging R&D capabilities in an academic environment for students and scientists. The Radiology department's research administration is also contained within this group of laboratories.

In the Dental School, DBME faculty are collaborating with physicians and molecular biologists in a range of applications spanning from dental and mandibular joint mechanics to engineering of biocompatible dental implants. DBME faculty members Edward Guo, Ph.D. and Helen Lu, Ph.D. and Dental School faculty member Jeremy Mao, DVM holds joint appointments in order to facilitate such endeavors.

The Biomedical Engineering Imaging Research Center



Within the MR Research Laboratories, Dr. Truman R. Brown, presides over the Biomedical Engineering Imaging Center, an academic and educational research facility. Andrew F. Laine, Ph.D., Associate Professor of Biomedical Engineering and Radiology (physics) and Director of the Biomedical Engineering imaging laboratories provides an expanding curriculum of courses at the undergraduate and graduate level and is an investigator in medical imaging research. Associated with this Biomedical center on the Health Sciences Campus are Andreas Hielscher, Ph.D., Associate Professor of Biomedical Engineering and Radiology, and Director, Biophotonics and Optical Radiology Laboratories; Elizabeth Hillman, Ph.D., Assistant Professor of Biomedical Engineering and Radiology and Director, Laboratory for Functional Optical Imaging; Elisa Konofagou, Ph.D., Assistant Professor of Biomedical Engineering and Radiology and Director, Ultrasound and Elasticity Imaging Laboratory, and Paul Sajda, Ph.D., Associate Professor of Biomedical Engineering and Director, Laboratory for Intelligent Imaging and Neural Computing. The BME facility includes imaging research laboratories for students and scientists, a video classroom and a state-of-the-art video conferencing facility, connecting Health Sciences with Morningside Campus Biomedical Engineering and worldwide.

Vision and Globalization

Thinking Globally

As it has become abundantly clear within our society, globalization has almost become a cliché. The concept of globalization was recently promoted by the wildly popular book “The World is Flat”, by Thomas Friedman, though not the first, and recognized by President Bollinger with his initiative in creating the Committee on Global Thought (CGT), led by Nobel

Laureate Joseph Stiglitz. This Committee is composed of fellows with background in philosophy, anthropology, foreign and security policy, law, political science, international affairs, history, East Asian languages and culture. A major goal of CGT is to create programs and sponsor events with a larger goal of "transforming Columbia….into a truly global university to serve the expanded needs of knowledge…" Some initial CGT activities include appointing faculty and graduate student fellows to CGT, inviting visiting fellows (e.g., Nobel Laureate in Literature Orhan Pamuk) during the fall semester of 2006, and other public symposia addressing global topics as the crisis of humanity in Darfur, global consequences of habeas corpus practices in the United States, and pilot courses on Global Governance, and Globalization, etc. These important topics address the foundational ideas of our lives and the structure of society in the United States and the world within which we live. Indeed, we have to be constantly aware of some of these important philosophical issues facing us in order to be an enlightened global citizen.

The Overarching Principle for SEAS Globalization—Acting Locally

Much of engineering activities embodied by SEAS faculties have been outstanding throughout its long history. Indeed, for an engineer, concrete research and development projects are the life blood of his/her profession; they are tangible, and they require concrete action. SEAS faculty have been well known and respected worldwide for the excellence and state-of-the-art work, and their contributions have had major societal impact throughout time. Today, Columbia as a whole, and SEAS in particular, have excellent opportunities to reach into major sectors of Asia, India, and elsewhere. No where is this stronger than the recent trend developed at SEAS to pursue multidisciplinary studies. Columbia University in the City of New York, with its strong core curriculum, and engineering school (SEAS), and its other major components such as Columbia University Medical Center (CUMC), College of Dental Medicine (CDM), etc, is poised to make major gains in translating and sharing what has been developed and learned from our multidisciplinary efforts over the past decade with exciting new interdisciplinary projects that address the needs of the world.

Through our International Exchange Program, we have also established student exchange and collaborative programs with other universities in Asia (Hong Kong, Beijing, Shanghai) and Europe (Netherlands, Germany, France, Switzerland and Austria).

Opportunities available to admitted students

Presidential Distinguished Fellowship- Tuition plus $35,000 Annual Stipend

The Fu Foundation School of Engineering and Applied Science awards several Presidential Distinguished Fellowships each academic year for incoming outstanding Ph.D., Doctor of Engineering Science, and M.S. leading to Ph.D. (M.S./Ph.D.) students. The Fellowships include tuition plus an annual stipend of $35,000 for up to 4 years including 3 months of summer research. This Fellowship is awarded to the selected students upon admission to the program.

National Science Foundation Fellowship

Several DBME students have been successful in obtaining Ph.D. fellowships from the National Science Foundation. The Graduate Research Fellowship provides three years of support for graduate study leading to research-based Master's or Doctoral degrees and is intended for students who are at the early stages of their graduate studies. Applications for this fellowship are submitted during the first year of graduate studies.