BIOMEDICAL ENGINEERING & PHYSIOLOGY
Carlos B. Mantilla, MD, PhD, Program Director
Armando Manduca, PhD, Associate Program Director

Ph.D. Degree
Vision
To prepare the next generation of biomedical scientists for leadership in medicine, academia and industry through integrated coursework and world-renowned research programs in the setting of the world's first and largest integrated group medical practice.

Minimum Requirements
A minimum of 42 credits of course work is required for a Ph.D. in the Biomedical Engineering & Physiology graduate program. Twenty-four credits must be taken from the basic Biomedical Engineering & Physiology courses and six credits must be taken from the core curriculum. Six credits must be taken in laboratory rotations. Additional credits may be selected from general courses and four major areas of emphasis in Biomedical Engineering & Physiology: biomechanics, biomedical imaging, molecular biophysics and physiology. Each area of emphasis requires certain additional courses to be taken.

Course Work
Core Courses (6 credits required)
- Core 6000 Responsible Conduct of Research 1 cr.
- Core 6050 Critical Thinking and Scientific Writing 2 cr.
- Core 6300 Molecular Biophysics 3 cr.

Track Requirements (24 credits required)
- BMEP 5200 Mathematics in Biomedical Engineering and Physiology 4 cr.
- BMEP 5452 Biomechanics 3 cr.
- BMEP 5704 Bio-Instrumentation and Signal Processing 3 cr.
- BMEP 5800 Introduction to Medical Imaging 6 cr.
- *BMEP 6700 Physiology from Cells to Organism 6 cr.
- BMEP 6600 Physiology & Biomedical Engineering Seminar 1 cr.
- BMEP 6650 Biomedical Engineering & Physiology Journal Club 1 cr.

*BMEP M.D.- Ph.D. students may exclude these in accordance to the M.D.-Ph.D. requirements.

Lab Rotations (6 credits maximum, a minimum of 3 rotations)
- MGS 5102 Lab Rotations (8 weeks) 2 cr.

BMEP M.D.-Ph.D. students satisfy this requirement with three one-month full-time rotations.

Research
- BMEP 6890 Research in Biomedical Engineering & Physiology

Must enroll every quarter once a thesis laboratory is selected.
Directed research projects under the supervision of a faculty advisor.
Biomedical Engineering & Physiology has four major areas of emphasis:

- **Biomechanics**

  **Emphasis Requirements (10 credits required)**
  
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<tr>
<th>Course</th>
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<th>Credits</th>
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<tbody>
<tr>
<td>BMEP 5250</td>
<td>Anatomy for Biomedical Engineering &amp; Physiology</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 5450</td>
<td>Fundamental Concepts in Biomechanics</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 5460</td>
<td>Finite Element Methods</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 5802</td>
<td>Advanced Principles of Biomechanics</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6470</td>
<td>Two-Dimensional Digital Signal Processing</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 6710</td>
<td>Numerical Methods in Biomedical Research</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6840</td>
<td>Laboratory Methods in Biomechanics</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6857</td>
<td>Tutorial in Cellular Mechanics</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6861</td>
<td>Tutorial in Skeletal Muscle Physiology</td>
<td>2 cr.</td>
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- **Biomedical Imaging**

  **Emphasis Requirements (minimum of 11 credits required)**

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<tr>
<th>Course</th>
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<tbody>
<tr>
<td>BMEP 5100</td>
<td>Radiological Health</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 5160</td>
<td>Radiation Physics</td>
<td>3 cr.</td>
</tr>
<tr>
<td>BMEP 5250</td>
<td>Anatomy for Biomedical Engineering &amp; Physiology</td>
<td>2 cr.</td>
</tr>
<tr>
<td>BMEP 5450</td>
<td>Laboratory Methods in Biomedical Image Processing</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 5460</td>
<td>Finite Element Methods</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 5550</td>
<td>Image Guided Procedures in Biomedical Applications</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 5740</td>
<td>Magnetic Resonance Imaging Systems</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6100</td>
<td>Medical Health Physics</td>
<td>2 cr.</td>
</tr>
<tr>
<td>BMEP 6151</td>
<td>Radiation Oncology Physics</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6302</td>
<td>Tutorial in Ultrasonic Imaging</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6304</td>
<td>Tutorial in Physiological Imaging</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6305</td>
<td>Seminars in Machine Learning</td>
<td>1 cr.</td>
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<td>BMEP 6420</td>
<td>Wave Propagations and Biomedical Applications</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6470</td>
<td>Two-Dimensional Digital Signal Processing</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 6490</td>
<td>Advanced Topics in Biomedical Image Processing</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6500</td>
<td>Special Topics in Imaging Science</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6704</td>
<td>Digital Signal Processing I</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 6705</td>
<td>Digital Signal Processing II</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 6710</td>
<td>Numerical Methods in Biomedical Research</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6730</td>
<td>Laboratory Methods in Magnetic Resonance Imaging</td>
<td>2 cr.</td>
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<tr>
<td>BMEP 6740</td>
<td>Advanced Topics in Magnetic Resonance Imaging</td>
<td>3 cr.</td>
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<tr>
<td>BMEP 6750</td>
<td>Magnetic Resonance Technical Seminar</td>
<td>1 cr.</td>
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<tr>
<td>BMEP 6770</td>
<td>Fuzzy Logic Theory and Applications</td>
<td>4 cr.</td>
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<tr>
<td>BMEP 6853</td>
<td>Readings in Biomedical Engineering</td>
<td>2 cr.</td>
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- **Molecular Biophysics**

  **Emphasis Requirements (minimum of 11 credits required)**

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<tr>
<th>Course</th>
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<tr>
<td>Core 6100</td>
<td>Chemical Principles of Biological Systems</td>
<td>3 cr.</td>
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  Choose at least one:
  
<table>
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<tr>
<th>Course</th>
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<tbody>
<tr>
<td>Core 6450</td>
<td>Molecular Pharmacology and Receptor Biology</td>
<td>2 cr.</td>
</tr>
<tr>
<td>BMEP 6350</td>
<td>Advanced Concepts in Molecular Biophysics</td>
<td>4 cr.</td>
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- **Additional Courses:**

  Choose at least three of the following:

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<tr>
<td>BMB 6000</td>
<td>Biological Macromolecules</td>
<td>3 cr.</td>
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<tr>
<td>BMB 6030</td>
<td>Data Analysis and Mathematical Modeling in Biomedical Research</td>
<td>1 cr.</td>
</tr>
<tr>
<td>BMB 6050</td>
<td>Biological Kinetics</td>
<td>3 cr.</td>
</tr>
<tr>
<td>BMB 6675</td>
<td>Protein Structure and Dynamics</td>
<td>2 cr.</td>
</tr>
<tr>
<td>Core 6150</td>
<td>Genome Biology</td>
<td>3 cr.</td>
</tr>
<tr>
<td>Core 6250</td>
<td>Molecular Cell Biology</td>
<td>3 cr.</td>
</tr>
<tr>
<td>Core 6400</td>
<td>Molecular Genetics</td>
<td>3 cr.</td>
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</table>
Emphasis Requirements (10 credits required)
BMEP 6830 Laboratory Methods in Physiology 2 cr.

Additional Courses:
Choose at least three of the following:
BMEP 6000 Tutorial in Exercise Physiology 2 cr.
BMEP 6300 Tutorial in Neurophysiology 3 cr.
BMEP 6855 Tutorial in Cardiovascular Physiology 3 cr.
BMEP 6856 Tutorial in Respiratory Physiology 3 cr.
BMEP 6858 Tutorial in Smooth Muscle Physiology 2 cr.
BMEP 6859 Tutorial in Renal Physiology 2 cr.
BMEP 6860 Tutorial in Endocrine Physiology 2 cr.
BMEP 6861 Tutorial in Skeletal Muscle Physiology 2 cr.
BMEP 6862 Tutorial in Neuromotor Control Physiology 2 cr.
BMEP 6870 Systems Physiology I 3 cr.
BMEP 6871 Systems Physiology II 3 cr.
BMEP 6872 Systems Physiology III 3 cr.

Qualifying Exams and Thesis Research
During the first two years of the program, each student is expected to select a laboratory and thesis advisor. This occurs largely as a result of lab rotations. By the beginning of the second year all students should select an area of emphasis. Students may combine areas. At the beginning of the second year, all students must take and satisfactorily pass a comprehensive qualifying exam, consisting of both written and oral components. The written qualifying exam focuses on required core curriculum courses taken in the first year and tests the conceptual integration of material in these courses. The oral qualifying exam will include a presentation of proposed research and tests the synthesis of course work and research interests.

During the second year of the program it is expected that all students will have selected a thesis advisor and a Thesis Advisory Committee with approval of the Biomedical Engineering & Physiology Education Committee. A written thesis proposal, presentation, and thesis committee discussion of the proposal must be completed by Dec 31 of the third year. Each student is expected to meet with their Thesis Advisory Committee at least twice a year to discuss progress towards their dissertation research. The Thesis Advisory Committee will decide when the research has progressed sufficiently so that a dissertation can be written, and the student will then write their dissertation and publicly defend it.
Biomedical Engineering & Physiology (BMEP) Track Courses:

**BMEP 5100f. RADIOLOGICAL HEALTH.** (2 cr; S-N; offered odd years; consent of instructor required prior to registration) Sturchio
Introduction to concepts of radiological health, philosophy and principles of radiation protection, interpretation of standards and regulations, and planning of facilities and activities.

**BMEP 5160f. INTRODUCTION TO RADIATION PHYSICS.** (3 cr; A-F; offered every other year, prereq calculus) Gorny, McGee
This is an introductory graduate course designed for those interested in the radiation sciences. The course will introduce the student to the basic concepts and physical principles that underlie modern radiation physics including atomic structure, radiation interactions of radiation with matter, introduction to cavity theory, biological effects of radiation (dose), x-ray production and dosimetry techniques.

**BMEP 5200su, f. MATHEMATICS IN BIOMEDICAL ENGINEERING & PHYSIOLOGY.** (4 cr; A-F) Manduca, Bajzer
This course will span two quarters. The first quarter will introduce mathematical topics used in biomedical engineering and quantitative physiological applications including a brief review of trigonometry and calculus, then covering linear algebra, vector analysis, complex variables and functions, Fourier series and transforms, and dimensional analysis. The second quarter will cover basic concepts in probability, ordinary differential equations, a basic introduction to MATLAB and an introduction to mathematical modeling of physiological systems. BMEP students register in the summer quarter only, but attendance is required both summer and fall. Students from other tracks may register for individual quarters or for the two-quarter course.

**BMEP 5250w. ANATOMY FOR BIOMEDICAL ENGINEERS.** (2 cr; S-N; offered odd years) Pawlina
Students dissect selected regions of the human body and learn correct names and locations of associated anatomical structures. Each student then gives a detailed presentation to the class of the region studied.

**BMEP 5300w. CELL AND NEUROPHYSIOLOGY.** (3 cr; A-F) Mantilla
This course will provide an understanding of basic concepts in cell and neurophysiology. The course will start with an introduction to cell physiology, electrophysiology and cell signaling. The focus will then move more specifically into sensory and motor systems.

**BMEP 5450f. LABORATORY METHODS IN BIOMEDICAL IMAGE PROCESSING.** (3 cr; A-F) Robb
Provides an introduction to important concepts in applied biomedical imaging, including digital processing of images, image signal characteristics, histogram analysis, domain processing, digital filters, image compression, reconstruction from projections, discussions of image composition, interactive 3D display, image processing and segmentation, registration and quantitative analysis. Practical applications in basic science and medicine are discussed. Students will use ANALYZE biomedical imaging software developed at Mayo to investigate these topics.

**BMEP 5452w. BIOMECHANICS.** (3 cr; A-F) Kaufman, Tschumperlin, Zhao
This course provides an overview of the mechanical properties and structural behavior of biological tissues in theory and in representative applications. Specific course topics include mechanics, structure and function relationships in tissues and organs, analysis of forces in human function and movement, kinematics of motion, and application of stress and strain analysis to biological tissues.

**BMEP 5453w,su. FUNDAMENTAL CONCEPTS IN BIOMECHANICS.** (3 cr; A-F) Kaufman
This course is an introduction to biomechanics and addresses the fundamental topics of kinematics and kinetics.

**BMEP 5460f. FINITE ELEMENT METHODS.** (3 cr; A-F; offered odd years; contact Dr. Manduca prior to registering for this course) Staff
This course introduces the fundamental concepts of the finite element methods and its major applications in biomechanics research.

**BMEP 5505s. PHYSIOLOGICAL CONTROL SYSTEMS I – MODELING AND SIMULATION.** (3 cr; A-F) Roy
This course covers dynamic system modeling, control, and simulation of some physiological systems. It uses MathWorks, Inc.'s Simulink package for simulation of the different open-and closed-loop physiological systems under study. Prerequisites are basic courses in physiology and differential equations.

**BMEP 5550s. IMAGE GUIDED PROCEDURES IN BIOMEDICAL APPLICATIONS.** (4 cr; A-F; prereq BMEP 5450 or equivalent) Robb, Holmes
An introduction to the concepts, methods and applications of image guided technology and interventions, including device tracking, advanced visualizations, workflow emulation and virtual reality simulations in biomedical research and clinical procedures.

**BMEP 5704s. BIOINSTRUMENTATION AND SIGNAL PROCESSING.** (3 cr; A-F). Daniel, Holmes
This course will provide an introduction to basic principles of bioinstrumentation and related signal processing. The course will begin with discussion of the basics of sensing and theoretical treatment of signals, with an emphasis on bioinstrumentation applications. The remaining portion of the course will focus on analog and digital signal processing, involving both theoretical analysis and practical implementation.

**BMEP 5740f. MAGNETIC RESONANCE IMAGING SYSTEMS.** (3 cr, A-F; offered odd years; prereq advanced calculus, Fourier analysis, and a course in modern physics) Riederer
Introduction to physics and engineering aspects of modern diagnostic magnetic resonance imaging (MRI).

**BMEP 5700f,w,s. INTRODUCTION TO MEDICAL IMAGING.** (6 cr, 2 cr. each quarter; A-F). McCollough, Leng.
This three-quarter course will introduce students to the fundamental physics, technical principles, and applications of medical imaging. The first quarter will focus on radiographic and fluoroscopic imaging and include an introduction to the radiation physics, dosimetry, and biology needed throughout the course. Qualitative and quantitative methods for assessing image quality will also be introduced. The second quarter will introduce tomographic reconstruction and radionuclide imaging, and focus specifically on x-ray computed tomography (CT), single-photon emission computed tomography (SPECT), and positron emission tomography (PET). The third quarter will cover ultrasound and magnetic resonance imaging (MRI), microscopy, and small animal imaging. BMEP students register in the fall quarter only, but attendance is required in the fall, winter, and spring quarters. Students from other tracks may register for individual quarters or for the three-quarter course.

**BMEP 5802s. ADVANCED PRINCIPLES OF BIOMECHANICS.** (3 cr; A-F; prereq BMEP 5453) An, Zhao
Advanced concepts of orthopedic biomechanics, including kinematics and kinetics, mechanics of deformable bodies, stress analysis, tissue engineering and fluid mechanics.

**BMEP 6000i. TUTORIAL IN EXERCISE PHYSIOLOGY.** (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Joyner
This course is designed for selected physiology graduate students who seek a broad overview in integrative physiology. The focus will be on presenting broad biological concepts related to integration, regulation, homeostasis, and the multitude of organ systems and how they adapt to various environmental and physical stresses. The course meets once a week for 1½ to 2 hours. It is taught using a collegial problem solving approach. Students take a major role in where the course goes. The course runs one full academic year.

**BMEP 6100s. MEDICAL HEALTH PHYSICS.** (2 cr; A-F; prereq BMEP 5100 or equivalent, or consent of instructor) Sturchio
Radiation protection philosophy and principles as applied to the medical environment: protection of patients, public, and employees; procedures for obtaining Nuclear Regulatory Commission license.

**BMEP 6151w. RADIATION ONCOLOGY PHYSICS.** (3 cr; A-F; prereq BMEP 5160) Beltran, Herman, Remmes
Physics principles of the application of ionizing radiation in radiation therapy, including radiation characteristics, dose calculation, treatment planning/dosimetry, brachytherapy and quality assurance.

**BMEP 6300. TUTORIAL IN NEUROPHYSIOLOGY.** (3 cr.; A-F; offered only once per year with consent of instructor required prior to registration) Sieck
This course will provide an understanding of the basic concepts in cell and neurophysiology. The application of current experimental methods and techniques will be emphasized. Classic papers from the literature will be assigned and discussed. Laboratory demonstrations and computer modeling will be included if class size permits.

**BMEP 6302i. TUTORIAL IN ULTRASONIC IMAGING.** (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Fatemi
Principles of ultrasound physics and interaction of ultrasound with biological tissues; principles and methods of tissue imaging using ultrasound; evaluating mechanical properties of tissue by ultrasound; measuring blood flow and tissue motion by Doppler method; artifacts in ultrasound imaging and in Doppler techniques; overview of recent and advanced techniques in medical ultrasound clinical applications of ultrasound.

**BMEP 6304i. TUTORIAL IN PHYSIOLOGICAL IMAGING.** (2 cr; A-F; consent of instructor required prior to registration) Ritman
Imaging of physiological function of in-situ organs, the limitations of those data and models needed to analyze such image data.

**BMEP 6305w. SEMINARS IN MACHINE LEARNING.** (1 cr; S-N) Erickson
This is a seminar course on machine learning, with particular focus on applications in medical imaging. The course will include discussions of seminal as well as more recent publications that are of interest to the field. There will also be discussion of challenges of practical application of methods, as well as potential pitfalls.

**BMEP 6350s. ADVANCED CONCEPTS IN MOLECULAR BIOPHYSICS.** (4 cr; A-F; offered even years) Sine
This course focuses on the biophysics of ion channels, solute transporters, molecular motors, elastic proteins, molecular recognition, protein dynamics and enzyme kinetics. A set of technical lectures will cover patch clamp recording, single channel kinetic analysis, x-ray crystallography, mass spectrometry and fluorescence spectroscopy. Didactic lectures are complemented by student presentations of a corresponding scientific paper.

**BMEP 6420s. WAVE PROPAGATIONS AND BIOMEDICAL APPLICATIONS.** (2 cr; A-F; prereq college physics) Fatemi
Wave propagation is a fundamental phenomenon of acoustics, electromagnetics, and optics. This course will emphasize the wave propagation of ultrasound and their applications to medical imaging and tissue property identification. In addition to linear wave propagation, nonlinear wave propagation and their potential medical applications will be studied.

**BMEP 6470f. TWO-DIMENSIONAL DIGITAL SIGNAL PROCESSING.** (4 cr; A-F; prereq BMEP 6704 or working knowledge of linear system theory and one-dimensional digital signal processing) Ottesen
Fundamentals of 2-D digital signal processing, including 2D discrete Fourier and Z-transforms, 2D discrete cosine transforms, and 2D linear and nonlinear Finite Impulse Response filters. Other topics covered are histogram equalization, edge-detection methods, morphology, compression routines and fuzzy logic filters. This class is a foundation for image processing. There will be homework and class projects.

**BMEP 6490s. ADVANCED TOPICS IN BIOMEDICAL IMAGE PROCESSING.** (3 cr; A-F; offered even years; prereq BME 5450 or equivalent experience/coursework) Manduca
An in-depth study of difficult problems in imaging science as they relate to biomedical images. Areas of study include image segmentation, image registration, texture analysis, shape description and matching, deconvolution, multispectral analysis and denoising.

**BMEP 6500i. SPECIAL TOPICS IN IMAGING SCIENCE.** (2 cr; A-F; prereq BMEP 5450, Core 6700; consent of instructor required prior to registration) Robb
Special topics in the imaging sciences applied to biomedical problems and data; including 3-D imaging, volume rendering, surface rendering, image segmentation, image registration and fusion, shape description and analysis, multi-spectral analysis and classification, virtual reality visualization, image modeling.

**BMEP 6600 PHYSIOLOGY & BIOMEDICAL ENGINEERING SEMINARS.** (1 cr; S-N; consent of instructor required prior to registration) Tschumperlin, Sieck
Presentations of research topics related to physiology & biomedical engineering. All BMEP students are required to attend seminars. In addition to attendance, students are required to give two short (30 min) presentations related to their own research projects, one prior to the start of winter quarter in their 3rd year and the second in their 5th year. Students should register in the quarter in which they give their second presentation.

**BMEP 6650 BIOMEDICAL ENGINEERING & PHYSIOLOGY JOURNAL CLUB.** (1 cr; A-F) Holmes
The Biomedical Engineering Journal Club provides a forum for discussion of recent advances in biomedical engineering and physiology. Development of critical reading and writing skills will be incorporated as they apply to manuscript and grant reviewing and writing. Each student is expected to present at least one paper per year. Faculty will be invited to participate as appropriate. Students are required to attend for 3 consecutive quarters in a given year - fall, winter and spring (register for course in spring.)

**BMEP 6700s,f,w. PHYSIOLOGY FROM CELLS TO ORGANISM.** (6 cr; 2 cr., each quarter A-F) J. Miller, Prakash
This three-quarter course will emphasize integration of structural (anatomical) and functional (physiological) concepts from the cellular level to the organismic level, thus helping the student understand how different cell types and organ systems normally work, how they work together in producing the day-to-day physiological features of the human body we observe, and gain fundamental insight into processes that contribute to disease states. The first quarter will focus on basic cellular physiology and pharmacology to lay the foundation for exploring the different organ systems, and will introduce and explore the cardiovascular system. The second quarter will introduce and explore the respiratory and endocrine systems. The third quarter will introduce and explore the musculoskeletal and gastrointestinal and genitourinary systems. In all quarters, the emphasis is on the anatomical and functional concepts that drive normal physiology and pathophysiology of major
disorders. BMEP students register in the summer quarter only, but attendance is required summer, fall and winter. Students from other tracks may register for individual quarters or for the three-quarter course.

BMEP 6704 DIGITAL SIGNAL PROCESSING I. (4 cr; A-F, offered annually) Ottesen
First of a two-part series starts with one-dimensional (1D) discrete time signals and systems, and the effects of sampling. It moves into the areas of 1D Discrete Fourier Transforms (DFT), Z-transforms, linear and circular convolutions and signal flow-graphs. Various methods for design of common analog filters and their conversion to 1D digital Infinite Impulse Response (IIR) digital filters. Also covered are 1D digital Finite Impulse Response (FIR) filters with linear phase characteristics. There will be homework, class projects, and an in-class final exam.

BMEP 6705f. DIGITAL SIGNAL PROCESSING II. (4 cr; A-F; offered 2013; prereq BMEP 6704 or consent of instructor) Ottesen
Topics covered are special 1D analog filters and their conversion to 1D digital equivalent filters; Advanced designs and structures of optimal FIR digital filters; spectral and cepstral analysis, and parametric and non-parametric estimation of signals; the effects and filtering techniques for different types of noise and introduction to discrete 1D ordered-statistic, homomorphic, Wiener, Golay-Savitzky and fuzzy logic filters. There will be homework, case studies and class projects.

BMEP 6710w. NUMERICAL METHODS IN BIOMEDICAL RESEARCH. (3 cr; A-F) Bajzer, Manduca
This course provides an overview of advanced mathematical and numerical methods commonly used in biomedical research including: theory and solution of ordinary and partial differential equations, common transforms, function fitting, interpolation and extrapolation, optimization and search algorithms, and filtering and time series analysis.

BMEP 6730w. LABORATORY METHODS IN MAGNETIC RESONANCE IMAGING. (2 cr; S-N; offered even years; prereq BMEP 5740, previous or concurrent registration) Edmonson
Introduction to MRI laboratory methods. Firsthand experience in basic and advanced MR image acquisition strategies, experimental tradeoffs, image reconstruction, and data interpretation.

BMEP 6740f. ADVANCED TOPICS IN MAGNETIC RESONANCE IMAGING SYSTEMS. (3 cr; S-N; offered even years; prereq BMEP 5740) Riederer
A technical study of advanced topics in contemporary magnetic resonance imaging (MRI). Topics to be discussed include vascular imaging and flow assessment, motion effects and compensation, echo-planar imaging, parallel acquisition, cardiac imaging, and diffusion.

BMEP 6750f,s. MAGNETIC RESONANCE TECHNICAL SEMINAR. (1 cr; S-N; offered odd years; consent of instructor required prior to registration) Riederer
Seminar held weekly consisting of a presentation of some contemporary technical research topic in magnetic resonance.

BMEP 6770f. FUZZY LOGIC THEORY AND APPLICATIONS. (4 cr; A-F; prereq a knowledge of Matlab and an interest in intelligent systems, like decision making, pattern recognition, classification and control) Ottesen
This course is intended for students and practicing scientists and engineers. It covers the applied concepts of fuzzy logic to several application areas. Fuzzy logic allows for the programming human experience into the computer. The reasoning used in fuzzy logic is similar to that of human reasoning. It allows for approximate values and inferences as well as incomplete or ambiguous data (fuzzy data) as opposed to only relying on crisp data (binary yes/no choices). Fuzzy logic is able to process incomplete data and provide approximate solutions to nonlinear problems that cannot be modeled in traditional ways. There will be homework, case studies and class projects.

BMEP 6830w. LABORATORY METHODS IN PHYSIOLOGY. (2 cr; A-F) Blanco
This course provides instruction and hands-on experience in the use of common methods and techniques in physiology. It will acquaint students with regulations, information sources, and ethical considerations of responsible animal use in research. Lab directors will teach students techniques such as appropriate handling, sampling, anesthesia, and surgery of animal subjects, with an emphasis on rodents, including transgenic methods and rodent models.

BMEP 6840f. LABORATORY METHODS IN BIOMECHANICS. (2 cr; A-F) Kaufman
This course is an introduction to biomechanics laboratory methods, covering techniques spanning from the in-vitro tissue level to in-vivo joint biomechanics. The course will include hands-on experience in material testing, motion tracking, force measurement, EMG measurement, device accuracy testing, and data processing. Students will also become familiar with IRB and IACUC study requirements.

BMEP 6853i. READINGS IN BIOMEDICAL ENGINEERING. (2 cr; S-N; consent of instructor required prior to registration) Staff
Review of contemporary topics in Biomedical Engineering literature to be arranged with individual staff members.
BMEP 6855su. TUTORIAL IN CARDIOVASCULAR PHYSIOLOGY. (3 cr; A-F; offered only once per year with consent of instructor required prior to registration) V. Miller
Students will be exposed to advanced topics in cardiovascular physiology with an emphasis on integrative control mechanisms in health and disease, structure and function, sex-based medicine and translational approaches to investigations. Students will be required to critically evaluate current literature, provide a historical overview of a specific topic and to write a review article on a topic of mutual interest to the group.

BMEP 6856i. TUTORIAL IN RESPIRATORY PHYSIOLOGY. (3 cr; A-F; offered only once per year with consent of instructor required prior to registration) Sieck
The goal of this course is to provide an in-depth account of the functional components of the respiratory system and their integration in health and disease.

BMEP 6857. TUTORIAL IN CELLULAR MECHANICS. (2 cr; A-F; consent of instructor required prior to registration) Tschumperlin
Detailed review of cellular structure and function relationships, diffusion, micro-mechanics, mechano-chemical signal transduction.

BMEP 6858i. TUTORIAL IN SMOOTH MUSCLE PHYSIOLOGY. (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Prakash
Students will be exposed to advanced topics related to smooth muscle signaling pathways, intracellular calcium regulation, pharmaco-mechanical coupling, etc.

BMEP 6859i. TUTORIAL IN RENAL PHYSIOLOGY. (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Romero
Renal hemodynamics, glomerular function, mechanisms and regulation of electrolyte transport.

BMEP 6860su. TUTORIAL IN ENDOCRINE PHYSIOLOGY. (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Eberhardt
This course focuses on several aspects of endocrine physiology, including mechanisms of hormone action, calcium homeostasis, glucose, and fatty acid metabolism, pituitary, thyroid and adrenal physiology, immunologic aspects of endocrinology, and endocrine effects on bone biology.

BMEP 6861. TUTORIAL IN SKELETAL MUSCLE PHYSIOLOGY. (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Sieck
The goal of this course is to explore muscle physiology from the protein-protein interactions that establish the molecular basis of muscle contraction to the biomechanics of movement.

BMEP 6862f. TUTORIAL IN NEUROMOTOR CONTROL PHYSIOLOGY. (2 cr; A-F; offered only once per year with consent of instructor required prior to registration) Sieck
The goal of this course is to explore modeling and analysis of complex physiological systems: respiratory control, sleep apnea, and locomotion. A laboratory session and journal reviews are also planned to prove some of the above concepts and their applications.

BMEP 6870f. SYSTEMS PHYSIOLOGY I. (3 cr; A-F) Romero
In Systems Physiology I; The Cell as a Complex Biological System – the students will obtain a broader view of traditional “Cellular Physiology.” All systems are made up of components which must communicate and respond. This course will focus on the fundamental organization that exists at the molecular, cellular, tissue, organism and population levels.

BMEP 6871w. SYSTEMS PHYSIOLOGY II. (3 cr; A-F) Sieck
Development, Growth and Regeneration – concepts of intracellular communications as taught in Systems Physiology I will be reinforced, and the concept of intercellular communication will be introduced as they relate to the development, growth, and regeneration of issues. Roles of stem and progenitor cells along with contributions from various model systems will be incorporated.

BMEP 6872s. SYSTEMS PHYSIOLOGY III. (3 cr; A-F) Ordog
The students will focus on the role of biological oscillators in cellular and higher-order physiological functions including cell cycle, circadian rhythms, neuroendocrine control of reproduction and metabolism, reproduction and germ cell development, as well as gastrointestinal and urogenital motor physiology. Topics discussed will include the role of transcriptional and epigenetic regulators, metabolic factors, and cellular signaling pathways in rhythm generations at the molecular and cellular level, interactions between oscillators to control complex organ and organismal functions, and mathematical models. This course builds on, reinforces, and extends concepts of intra- and intercellular communication discussed in the preceding Systems Physiology courses.
BMEP 6875(8875) su. PHYSIOLOGICAL CONTROL SYSTEMS II – STABILITY AND OPTIMIZATION. (3 cr; A-F; prereq BMEP 5505 or a basic course in control systems or dynamic system modeling) Staff
The course covers stability, identification, and optimization of some physiological systems. It uses Matlab and Simulink to analyze the physiological systems under study. A laboratory session is included to prove identification and estimation concepts.

BMEP 6876(8876) w. ADAPTIVE AND NONLINEAR PHYSIOLOGICAL SYSTEMS. (3 cr; A-F; prereq BMEP 6875) Staff
The course covers the modeling and analysis of the following complex physiological systems: Respiratory Control, Cardiac Dysrhythmias, Sleep Apnea, Neutrophil Density Regulation, Cardiovascular Variability, and Circadian Rhythms. Adaptive and nonlinear control concepts are explained and applied to these physiological systems, and where Matlab and Simulink are used for simulation. A laboratory session and journal reviews are also planned to prove some of the above concepts and their applications.

BMEP 6878(8878) su. TUTORIAL IN BONE PHYSIOLOGY. (3 cr; A-F; offered only once per year with consent of instructor required prior to registration) Oursler
Lectures and discussions in physiology of both normal and abnormal bone. Classes are a combination of lectures and current topical literature. Topics will vary, depending on the interest of enrolled students.

Research

BMEP 6890 RESEARCH IN BIOMEDICAL ENGINEERING AND PHYSIOLOGY. (S-N) Staff
Opportunities in research for Ph.D. students to be arranged with individual staff members. Must enroll every quarter once a thesis laboratory is selected.