Biomedical Engineering Continues to Make the Future

Anticipating the Needs of Interface Engineering and Clinical Medicine

By Sergio Fantini, Caoimhe Bennis, and David Kaplan

Biomedical engineering (BME) continues to make the future, not just respond to the present, by anticipating the needs of interface engineering and clinical medicine. In many respects, BME is the educational mode of the future, fostering collaboration among disciplines at its core by building on basic concepts in engineering and biology. We strive to educate where the needs, opportunities, and jobs are and will be in the future. The bridge between engineering, biology, and medicine is a growing link, and there is no sign that this interface will slow. With an aging population, dynamic changes in health care, as well as global economies and related themes upon us, we are only at the very beginning of the impact that BME will have on medicine and the quality of life. Those of us in BME are excited to be setting this agenda and welcome your participation. In part, this is why we have designed our BME major to cover both the depth and breadth, always a challenge, but one that we are committed to. The depth of the design projects, research experience, coursework, study abroad options, and internships all convenes to establish a solid foundation for our students as they embark on their career paths.

—David Kaplan, chair, Biomedical Engineering Department, Tufts

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Biomedical engineering (BME) is a discipline of growing importance in society and is a vital and growing part not only of the Boston area but also of the whole U.S. territory infrastructure—industry, academics, and hospitals. There has been a major expansion in the field of BME for the past few years. This expansion is due to many factors, including

- scientific and technological advances in molecular and cell biology, materials science, and engineering disciplines
- the increasing recognition of the role of interdisciplinary strategies to solve complex biomedical problems
- the aging of the population leading to increasing health-care needs and the associated demands and costs.

FIGURE 1 The Biomedical Engineering Department at Tufts School of Engineering Administration Building.

The BME Department at Tufts University (Figure 1) reflects these themes and offers comprehensive education and research opportunities to students, faculty, and industry interested in pursuing this topic.

Established at Tufts University in September 2002, the BME Department is located at the Science and Technology Center, a state-of-the-art research and teaching facility, which also houses the cutting-edge interdisciplinary research activities of the Tissue Engineering Resource Center (TERC), a National Institutes of Health-funded research resource for biomedical technology.

The department actively coordinates and interfaces with other departments, schools, and programs at the university to facilitate BME programs and opportunities in areas such as biomedical instrumentation, bioengineering, biotechnology, and systems biology. The BME program draws from core disciplines such as engineering, biology, computer science, physics, chemistry, and physiology emphasizing an interdisciplinary approach to research and education. In fact, a strong emphasis is placed on education at the interface of multiple disciplines, and interactions with faculty in arts and sciences and the professional schools, including veterinary medicine, medical school, dental school, and nutrition school, are fostered to promote collaborations and cultural exchange. We give an overview of the engineering of regenerative medicine and sensing systems at various focused laboratories within Tufts University below.

Regenerative Medicine—Biomaterials and Tissue Engineering

Combining knowledge in cell and molecular biology, physiology with biomaterials, biomechanics and biotransport phenomena, regenerative medicine aims to understand the mechanical, structural, and biological processes associated with designing and developing systems to repair or replace damaged organs and tissues. The current research activities address the aspects of cellular engineering, biomaterials, and tissue engineering.

Prof. David Kaplan (Figure 2) directs biomaterials and tissue engineering at TERC. The Kaplan Laboratory research focuses on biopolymer engineering to understand structure–function relationships, with emphasis on the studies related to self-assembly, biomaterials engineering, tissue engineering, and regenerative medicine. The studies focus on a variety of structural proteins, including collagens, elastins, resilins, and silks. The laboratory also utilizes the biopolymers mentioned earlier for studies related to controlled drug delivery. Recent studies have focused on the use of complex three-dimensional (3-D) tissue culture systems to establish and study diseases associated with kidney, obesity, diabetes, and cancers. These tissue systems are also used for therapeutic screening.

Research at TERC includes, but is not limited to: scaffold designs to control stem cell differentiation; designing new scaffolds with consideration for mechanical function, rates of matrix remodeling, cell responses, and tissue outcomes; advanced bioreactor systems to impart controlled environmental stimuli to cells cultured on scaffolds; and the characterization of tissues through nondestructive imaging.

Prof. Catherine Kuo (Figure 3) directs tissue engineering and embryonic development research in the Kuo Laboratory. The overarching research theme in this laboratory is that embryogenesis-inspired regeneration strategies will result in accelerated stem cell differentiation and musculoskeletal tissue development. The primary model tissues in this research are tendon and ligament, with the focus being extended to associative tissues of mesenchymal origin. In this vein and with the long-term goal of engineering living tissue replacements, Prof. Kuo's primary research interests are in three

FIGURE 2 David Kaplan.

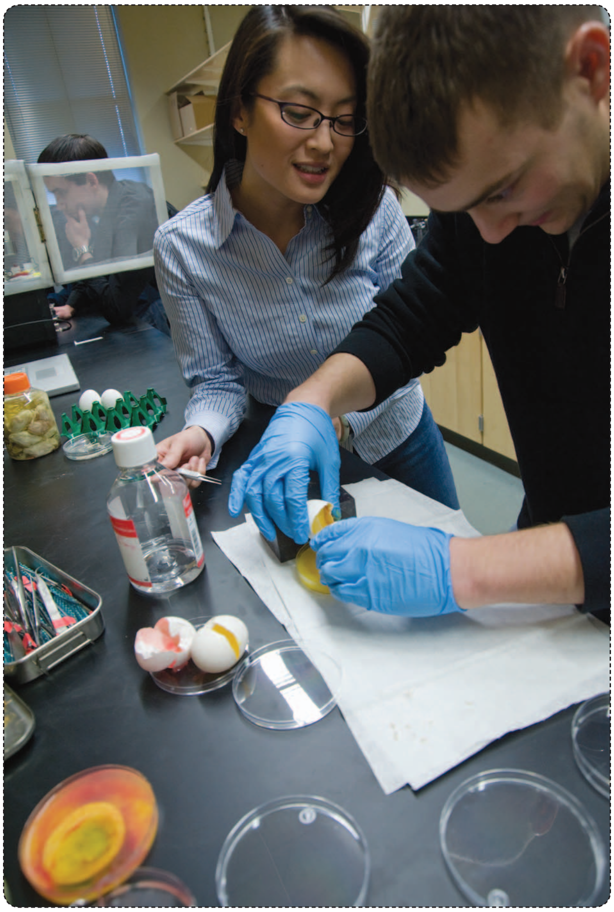

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FIGURE 3 The overarching research theme in the Kuo Laboratory is that embryogenesis-inspired regeneration strategies will result in accelerated stem cell differentiation and musculoskeletal tissue development. Catherine Kuo looks on as graduate student Charles Banos studies chicken embryos.

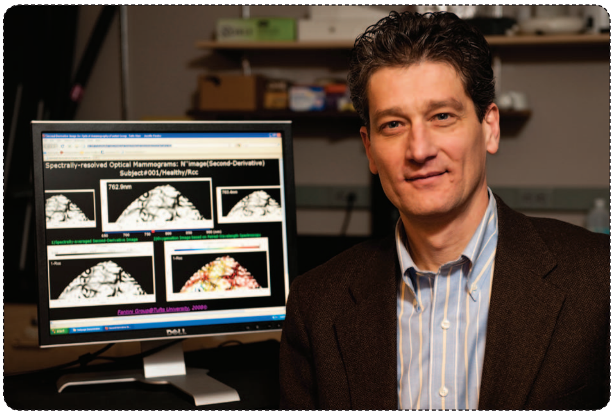

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FIGURE 4 Fantini, professor of biomedical engineering at the optical mammography laboratory of the Tufts University BME Department.

major areas: development of 3-D culture models with which to study developmental biology and disease mechanisms of engineered tissues of mesenchymal origin; chemo- and mechanoregulation of embryonic progenitor and adult stem cell differentiation and tissue development (in vivo and engineered in vitro); scaffold development and characterization of structure–function relationships

The interdisciplinary nature of research in the Kuo Laboratory merges the expertise from various disciplines of engineering (materials science and mechanical and electrical engineering), biology (developmental, molecular, and stem cell biology), and medicine (orthopedics).

Cardiovascular tissue engineering in Prof. Lauren Black's Laboratory is focused on understanding the biophysical signaling mechanisms responsible for the development of healthy and diseased myocardium inclusive of mechanical stress/strain, electrical stimulation, and cell–cell/cell–matrix interactions. The ultimate goal of his research is to design and develop new methods for repairing diseased or damaged myocardium. The work in his laboratory spans the following areas.

- The use of novel methods, such as whole organ decellularization, to study the role that the local extracellular environment (matrix stiffness, morphology, and composition) plays in the progression of myocardial disease and how it relates to the potential effectiveness of cell therapy-based methods of cardiac repair.
- Investigation into the physicochemical signaling mechanisms (growth factors, electrical stimulation, and mechanical stimulation) responsible for the development of healthy myocardium from cardiac precursor or stem/progenitor cells.
- The design, development, and evaluation of new methods for cardiac repair following myocardial infarction (heart attack) and heart failure, inclusive of tissue-engineered ventricular myocardium created in vitro for implantation in vivo.

Prof. Qiaobing Xu focuses on nanoscience for biomedical application, aimed at developing new synthetic materials, such as a library of lipidlike molecules, for the delivery of therapeutic biomacromolecules (for example, proteins and messenger RNA). Current research also investigates the use of drug delivery to stimulate host immune system for cancer vaccine applications and the development of micro/nanofabrication tools for tissue engineering applications.

Sensing Systems—Medical Instrumentation and Measurement

The development of new methodologies for image acquisition and processing is necessary to establish new procedures for monitoring therapy response and clinical diagnosis. The current research activities aim to create imaging systems that can provide continuous, noninvasive, inexpensive monitoring for a variety of organs and tissues in clinical abnormalities. Specific research lines in this area include the following:

- *Diffuse Optical Imaging and Spectroscopy led by Prof. Sergio Fantini*: Diffuse optical imaging is a noninvasive technique for low-resolution studies of biological tissues at a macroscopic scale. Research activities in Prof. Fantini's group (Figure 4) include near infrared spectroscopy of tissue for diagnostic, functional, and imaging applications. Research activities include quantitative modeling of light propagation in optically turbid media, the design of optical

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FIGURE 5 Prof. Kaplan (right) and Prof. Fiorenzo Omenetto in Omenetto's Laboratory at the Tufts Science and Technology Center. They are researching the optical properties of silk.

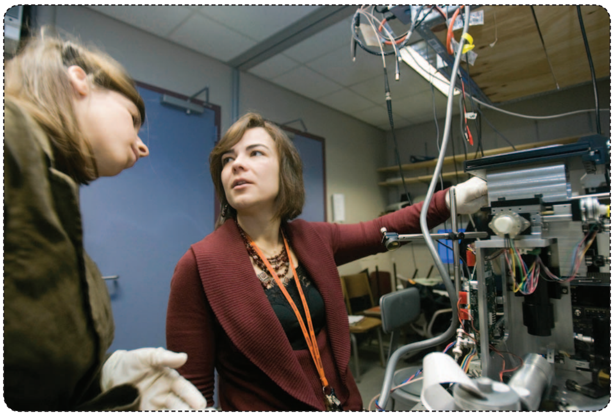

FIGURE 6 A doctoral student, Joanna Xylas (left), listens to Prof. Irene Georgakoudi in the laboratory. Georgakoudi's research focuses on the development of novel optical technologies for disease diagnosis and tissue engineering applications.

instrumentation for medical imaging, the development of novel near infrared spectroscopy, and imaging techniques for medical diagnostics.

- *Optics in the Development of Biomedical Devices led by Prof. Mark Cronin-Golomb*: Prof. Cronin-Golomb's research activities involve the development of novel instrumentation for engineering biomedically relevant structures and investigating cellular interactions on a microscopic scale. One example is the use of optical tweezers to investigate the forces that provide the structural integrity of cancers. The research group is interested in the effects of photodynamic therapy on the adhesion of cancer cells to each other and the possible links to metastasis. Prof. Cronin-Golomb's research group is also involved in a project on the use of photonic band gap engineering and nonlinear optics to make continuous-wave terahertz optical sources for biomedical imaging.
- *Ultrafast Nonlinear Optics and Biophotonics led by Prof. Fiorenzo Omenetto*: The use of nonlinear optics, femtosecond laser pulse control, and appropriately designed (micro and nano) structures in new materials provides a rich field of research and offers unprecedented opportunity for technological advances and new diagnostic approaches. Prof. Omenetto's research group (Figure 5) is specifically interested in engineered and biomimetic optical materials (such as photonic crystals and photonic crystal fibers) and novel/unconventional organic, sustainable optical materials for photonics, and optoelectronics. In particular, in close collaboration with Prof. Kaplan's resident biopolymer expertise, we have pioneered silk optics, and we are reinventing silk as a green material for photonics and high-technology applications.
- *Optical Diagnostics for Diseased and Engineered Tissues (ODDET), led by Prof. Irene Georgakoudi*: The ODDET group (Figure 6) focuses on the development of optical spectroscopic imaging approaches to monitor and characterize biochemical and morphological aspects of tissue in noninvasive ways. The work relies heavily on optical instrument development and quantitative data analysis approaches that often involve modeling and understanding of the detailed interactions between light and biological matter. Research areas include in vivo flow cytometry; development of novel optical biomarkers for early cancer detection; and optical monitoring of cell–matrix interactions in engineered tissues.

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Conclusions

The BME at Tufts University brings together experts from diverse fields of engineering, medicine, and science to offer comprehensive education and research opportunities to students, faculty, and industry. To achieve a comprehensive learning experience, students undertake work experience, focused course work, international study experiences, and internships within a true collaborative environment. The current research activities aim to create imaging systems that can provide continuous noninvasive, inexpensive monitoring for a variety of organs and tissues in clinical abnormalities, and to develop novel paradigms in biomaterials, tissue engineering, and regenerative medicine. Hence, BME continues to make the future by anticipating the needs that interface engineering and clinical medicine. For more information on biomedical research at Tufts University, please refer to our Web site at engineering.tufts.edu/bme/.

Serigio Fantini (Sergio.Fantini@tufts.edu) *is with the Department of Biomedical Engineering, Tufts University.* ***Caoimhe Bennis (cbennis@partners.org)*** *is with Motion Analysis Lab, Spaulding Rehabilitation Boston.* ***David Kaplan (David.Kaplan@tufts.edu)*** *is with the Department of Biomedical Engineering, Tufts University.*