33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

A Disease-Centered Approach to Biomaterials Education and Medical Device Design

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Abstract— **This paper describes the development of a novel elective course in biomaterials which integrates clinical medicine with engineering principles. In this educational approach, students are first introduced to disease pathologies and clinical needs, and then exposed to engineering technologies that can fulfill unmet needs. The course is directed toward the question, "Where are clinical needs most urgent, and how can engineering be applied to meet those needs?" This clinically-oriented, disease-centered approach is valuable for science and engineering education, as it relays to students the centrality of engineering in solving the world's most pressing healthcare problems.**

I. Introduction

THE field of biomaterials science currently faces an unprecedented opportunity to improve and save the lives of millions worldwide. A unique integration of chemistry, biology, engineering, and medicine, biomaterials science brings novel materials to bear on medical problems. The past few years have witnessed an explosion in the field of biomaterials, with an expansion of both the compositions and the applications of medical implant materials [1]-[2]. While traditional biomaterials have been designed from polymers, ceramics, and metals, the newest generation of biomaterials incorporates biomolecules, therapeutic drugs, and living cells. At the same time that biomaterials science is advancing in the laboratory, the incidence of serious diseases is rising in the global community. The increasing proportion of older people in the global population is contributing to the increase of age-associated chronic diseases, including heart disease and cancer. Infectious diseases also represent a significant burden to global health; mortality from HIV/AIDS, tuberculosis, and infectious gastrointestinal diseases remains high. Physicians and biomedical researchers must be ready to address growing health-care needs in every part of the world. Innovative biomedical materials will only reach the clinic if these technologies solve pressing clinical problems.

Biomaterials scientists who wish to impact global health must first understand where the most urgent clinical needs lie. Translation of innovative technologies into clinical usage will require close collaboration between physicians and biomaterials scientists, so that scientists can address unmet clinical needs, and physicians can appreciate novel technologies. This paper describes the design of a new biomaterials elective course that exposes students to both disease pathologies and engineering design. The course aspires to bridge the gap between the laboratory and the clinic, by identifying needs for biomedical materials in the context of the most prevalent diseases worldwide. A textbook has been written and published to support this instructional approach [3]; the book discusses research priorities for new biomaterials based on the most prevalent global diseases, and may be used as the basis for an innovative elective in biomedical engineering.

Manuscript received April 15, 2011.

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II. Course Design

One of the most important means for gauging the global burden of disease and the effectiveness of the global healthcare system, as well as the biomedical research enterprise, is to measure how many people die each year, and track the causes of death. Therefore, the biomaterials elective course is organized according to the World Health Organization's report of the top 10 causes of death worldwide [4], and lays out opportunities for biomaterials scientists and physicians to tackle each of these leading contributors to mortality (Table 1). The introductory unit discusses the global burden of disease. Each of the subsequent ten units focuses on a specific disease process, beginning with the leading cause of death worldwide, cardiovascular disease. Every unit begins by describing the underlying pathology of the disease, and then discusses prospective research areas for novel biomaterials to modify the disease process. Diseases addressed in the course include coronary artery disease, HIV/AIDS, pneumonia, cancer, stroke, and gastrointestinal disease, as well as traumatic injuries. The course also covers a wide range of technologies necessary to defeat these diseases, including imaging agents, drug delivery platforms, biosensors, tissue engineered constructs, antimicrobials, and vaccines.

The present course provides a complimentary perspective to existing biomaterials courses and textbooks. While many courses and textbooks take a technology-centered approach to biomaterials education [5]-[6], the present course takes a disease-centered approach. The course addresses the question, *"Where are clinical needs most urgent, and how can biomaterials be designed to meet those needs?"* The course provides detailed descriptions of relevant disease pathologies, to allow engineers to understand clinical issues.

TABLE I
SYLLABUS FOR A NOVEL BIOENGINEERING ELECTIVE COURSE

BIOMATERIALS FOR CLINICAL APPLICATIONS

UNIT 1: Introduction
- 1-1. The worldwide burden of disease
- 1-2. The necessity for novel biomedical materials

UNIT 2: Coronary heart disease
(7.20 million deaths per year, 12.2% of total)
- 2-1. Pathology of heart disease
- 2-2. Biomaterials as bioactive stents
- 2-3. Biomaterials as degradable stents
- 2-4. Biomaterials for cardiac regeneration

UNIT 3: Stroke and other cerebrovascular diseases
(5.71 million deaths per year, 9.7% of total)
- 3-1. Pathology of stroke
- 3-2. Biomaterials for improved brain imaging
- 3-3. Biomaterials for nerve regeneration

UNIT 4: Pneumonia and lower respiratory infections
(4.18 million deaths per year, 7.1% of total)
- 4-1. Pathology of lower respiratory infections
- 4-2. Biomaterials as novel antibiotics

UNIT 5: Perinatal conditions
(3.18 million deaths per year, 5.4% of total)
- 5-1. Prematurity and low birth weight conditions
- 5-2. Biomaterials as pulmonary surfactant
- 5-3. Biomaterials for improved circulatory and respiratory support devices

UNIT 6: Chronic obstructive pulmonary disease
(3.02 million deaths per year, 5.1% of total)
- 6-1. Pathology of COPD
- 6-2. Biomaterials for lung regeneration

UNIT 7: Diarrheal diseases
(2.16 million deaths per year, 3.7% of total)
- 7-1. Pathology of diarrheal disease
- 7-2. Biomaterials for pathogen detection
- 7-3. Biomaterials for control of microbial contamination

UNIT 8: HIV/AIDS
(2.04 million deaths per year, 3.5% of total)
- 8-1. Pathology of HIV/AIDS
- 8-2. Biomaterials as synthetic vaccines
- 8-3. Biomaterials as vaccine adjuvants

UNIT 9: Tuberculosis
(1.46 million deaths per year, 2.5% of total)
- 9-1. Pathology of tuberculosis
- 9-2. Biomaterials as novel anti-tuberculosis therapeutics

UNIT 10: Trachea, bronchus, lung cancers
(1.32 million deaths per year, 2.3% of total)
- 10-1. Pathology of lung cancer
- 10-2. Biomaterials for tumor imaging
- 10-3. Biomaterials for targeted delivery of chemotherapy

UNIT 11: Road traffic accidents
(1.27 million deaths per year, 2.2% of total)
- 11-1. Traumatic injuries
- 11-2. Biomaterials for bleeding control
- 11-3. Biomaterials for wound closure

UNIT 12: Conclusion
- 12-1. Traditional biomaterials versus new biomaterials
- 12-2. Designing materials with clinical needs in mind

This novel disease-oriented approach provides a necessary clinical context for biomaterials development, and inspires new innovations in medical technology. This perspective may provide useful insights for biomaterials scientists and engineers, as well as physicians and surgeons who utilize emerging biomedical materials technologies in their clinical practice. Such an approach can aid researchers and administrators in allocating resources and setting research priorities, to ensure that biomaterials advances and new technologies actually fulfill an unmet clinical need. In addition, the disease-centered approach is valuable for science and engineering education, as it conveys to students the excitement and relevance of materials science to solving the world's most pressing healthcare problems. Finally, this approach enables scientists and engineers to converse knowledgably with clinicians regarding disease processes and technological solutions. This clinically-oriented, disease-centered approach is valuable for science and engineering education, as it relays to students the centrality of engineering in solving the world's most pressing healthcare problems.

III. COURSE IMPLEMENTATION

The disease-oriented biomaterials course was implemented as an elective in the fall semester of 2010, within the Department of Chemical Engineering at the University of Delaware. Students included junior and senior undergraduates majoring in chemical engineering and quantitative biology, as well as first-year graduate students in chemical engineering. The course was instructed by a physician-bioengineer (the present author). Each lecture began with a patient presentation to illustrate a specific disease process (coronary artery disease, stroke, tuberculosis, etc.), and then proceeded to describe biomaterials for alleviating the disease. Lectures additionally incorporated clinical trials for the evaluation of novel biomaterials. Students completed case studies of new biomaterials, and learned of wider applications for emerging biomaterials. For instance, students recognized that targeted drug delivery platforms for the treatment of lung cancer could also be applicable to a wide variety of cancers; nerve regeneration biomaterials for the treatment of stroke could also be applicable to spinal cord injury; and intracellular drug delivery platforms for the treatment of tuberculosis could also be applied to other intracellular pathogens.

Students completed a capstone project for the course, in which they worked in teams to conceptualize an original biomaterial to address an unmet clinical need. The students successfully grasped the notion of biomaterials design for clinical utility. Students identified prospective research areas for novel biomedical devices, and teams devised biomaterials for a range of medical applications in oncology, rheumatology, diabetes, and orthopedics. Team projects included mucoadhesive nanoparticles for focal therapy of colon cancer; targeted nanoparticles for imaging of inflammation; an oral drug delivery system for glucose-responsive release of insulin to treat diabetes; multi-functional nanoparticles for chemotherapy of pancreatic cancer; filomicelles for combination chemotherapy of breast cancer; allografts for reconstruction of the anterior cruciate ligament following injury; and anti-inflammatory constructs for cartilage regeneration to treat osteoarthritis.

Student responses to the disease-oriented biomaterials course were extremely positive, as reflected by anonymous student evaluations of the elective. Students enjoyed the multidisciplinary perspective, with the combination of clinical and technical viewpoints. One student appreciated the "combination of materials design and evaluation from both an engineering perspective and a disease-specific application." Another student commented, "it was a very good course which gave good insight on the current application of biomaterials." Yet another student valued the course "because it gave a more well-rounded curriculum." Several students described the course material as "interesting" and "stimulating," and complimented the course for using "real-life examples." A student stated that "the clinical aspect added by the lectures was extremely interesting and added a lot to the course," while another remarked, "I really liked how [the instructor] used patient presentations when introducing new topics." A student observed that the course incorporated "a good mix of bio, engineering, and current research." Many students also enjoyed the capstone project and the design aspects of the course: one student said that the "biomaterials project was interesting in trying to understand all of the aspects in designing a biomaterial." Importantly, one student stated the experience "inspired a lot of interest into the field of biomaterials for me."

IV. Conclusion

Biomaterials scientists have the unique ability and responsibility to create technologies that will find significant clinical applications. It has been predicted that "ultimately, almost every human in technologically advanced societies will host a biomaterial" [7]. The emerging class of biomedical materials, including surface-modified biomaterials, smart biomaterials, bioactive biomaterials, and tissue engineered materials, will have improved properties of biocompatibility, tunability, and biological functionality. When biomaterials are designed with an eye toward clinical needs, the resulting innovations will address the world's most prevalent diseases, yet will also find utility for related disease processes.

The proposed elective course encourages disease-oriented biomaterials research and education, so that emerging technologies can be most effectively deployed from "bench to bedside" to defeat existing diseases. The course was extremely successful during initial implementation, and this teaching approach will be continued in biomaterials electives at the University of Delaware and Harvard University. Such a course can be valuable for bringing both a clinically-oriented perspective and a design-oriented perspective to biomedical engineering. The global imperative for such an educational approach is clear, now more than ever.

Acknowledgment

S. K. Bhatia thanks the faculty and students of the University of Delaware College of Engineering and the Harvard University School of Engineering and Applied Sciences for their support of innovative educational approaches.

References

[1] N. Huebsch and D. J. Mooney, "Inspiration and application in the evolution of biomaterials," *Nature,* vol. 462, pp. 426-432, Nov. 2009.
[2] K. Ghosh and D. E. Ingber, "Micromechanical control of cell and tissue development: implications for tissue engineering," *Adv. Drug Deliv. Rev.,* vol. 59, pp. 1306-1318, Nov. 2007.
[3] S. K. Bhatia, *Biomaterials for Clinical Applications.* New York, NY: Springer, 2010.
[4] World Health Organization, *The Global Burden of Disease: 2004 update.* Geneva, Switzerland: WHO Press, 2008.
[5] B. D. Ratner, A. S. Hoffman, F. J. Schoen, and J. E. Lemons, *Biomaterials Science, 2nd Edition: An Introduction to Materials in Medicine.* San Diego, CA: Academic Press, 2004.
[6] J. S. Temenoff and A. G. Mikos, *Biomaterials: The Intersection of Biology and Materials Science.* Upper Saddle River, NJ: Pearson Prentice Hall, 2008.
[7] A. G. Gristina, "Biomaterial-centered infection: microbial adhesion versus tissue integration," *Science,* vol. 237, pp. 1588-1595, Sept. 1987.