LGBTQI AND FRIENDS EVENT IN ATLANTA, SIG UPDATES

BIOMATERIALS DEFINITION GATHERING IN CHENGDU

BIOMATERIALS FORUM

OFFICIAL NEWSLETTER OF THE SOCIETY FOR BIOMATERIALS

THIRD QUARTER 2018 • VOLUME 40, ISSUE 3

ALSO INSIDE

AN INTERVIEW WITH SUSAN THOMAS

HISTORICAL FLASHBACK BY TOM HORBETT

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BIOMATERIALS FORUM

The official news magazine of the **SOCIETY FOR BIOMATERIALS** • Volume 40, Issue 3

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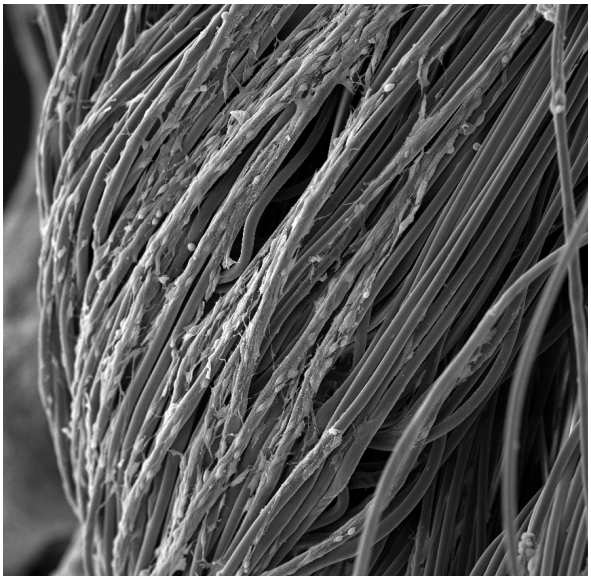

ON THE COVER

The cover image, provided by Xiaoqi Tang of Prof. Martin W. King's Lab in the Department of Textiles Engineering at North Carolina State University, shows 3D growth of 3T3 cells on PLA fibers, resembling a wheat-like structure.

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THE TORCH

NEWS & UPDATES

From the Editor

By Guigen Zhang, Editor, SFB Forum

On the day of the 2018 World Cup final, neuroscientist Brenda Milner turned 100. It is comforting to hear such news because it makes us researchers feel young, or babyish.

Okay, this is not why I want to talk about her here. The true reason is this: Because of Dr. Milner, our understanding of the nervous system has changed dramatically. She has made major contributions to the understanding of the role of the frontal lobes in memory processing, in the area of organizing information, which plays a key role in emotional responses, hearing, memory and speech. Through speculation that there are different types of learning and memory, each dependent on a separate system of the brain, Dr. Milner demonstrated two different memory systems—episodic memory (the memory of autobiographical events: times, places, associated emotions, and other contextual who, what, when, where, and why knowledge) and procedural memory (a part of the long-term memory that is responsible for knowing how to do things, also known as motor skills). She showed us that knowing how to do something and knowing that you've learned something are controlled by different parts of memory systems, providing the neurological basis for the argument "learning how is not like learn that" made by British philosopher Gilbert Ryle, which I often quote in my classes in hopes of stimulating a proactive learning attitude in students.

In learning more about Dr. Milner, I came across a 2006 interview by Chenjie Xie, a medical student at McGill, in the *McGill Journal of Medicine*. Below I want to bring to our students' attention some of her words of wisdom.

How do you work with your students in coming up with a research project?

I've never given a student a specific project. I tell them what we are working on; I throw ideas out to them. Sometimes, they come back with things that don't quite work, but along the way, they find out what they are interested in. Graduate students are supposed to be learning what they are interested in. If they are interested in the general area I'm working in, I expose them to everything that we are concerned with and the things we are tackling. Then, I ask them to do quite a bit of reading. They may come back with an idea that is not very well formulated, and I can help them formulate it. But I am not going to tell them what experiments they should do.

What qualities do you look for in your graduate students? What kind of skills do you encourage them to develop?

They have to have a lot of curiosity. They must not have any illusions about science. They must not have any romantic notion that they are going to make a great discovery once a month or even once a year. There's an awful lot of routine in any job. This can be very boring if you don't have the right attitude. I think people have to be very patient.

For students learning how to write scientifically, what advice would you give them?

I've read theses in which the experiments are good, but the writing just made my hair stand on end. The really big thing is to anticipate your readers' needs. I remember working on my thesis. I prided myself on my writing and I remember giving Hebb [my advisor] the historical introduction to my thesis, which I was quite proud of. He gave it back to me and said, "Can't understand it! Can't follow it!" I was so insulted; I didn't look at this thesis for about a month. And then I thought, "I'll show him!" I started realizing what the problem was. It was all there, but you have to anticipate your readers' needs. You have to tell them something in advance if they'll need it in the next paragraph. You mustn't tell them something at the end that they needed earlier on. You know these things, because it's your work and it's all in your head, but the poor reader doesn't have your head. This is absolutely a huge thing that people have to learn, and then it becomes second nature. After showing the second draft to Hebb, he said, "This is excellent."

In closing, let me briefly tell you what we have prepared for you in this issue. You will hear from SFB President Andres Garcia, read about member news, a staff update, student news, SIG updates, an LGBTQI event, industry news, and a book review. In the "Historical Flashback" column, we provide you some reflections by Tom Horbett. In the "Meet the Rising Stars" column, we feature an interview with Susan Thomas, the 2018 SFB Young Investigator Awardee. In the Letter To The Editor column, we share with you the insightful viewpoints of Jack Ricci. We also share highlights from the conference on definitions of biomaterials held in Chengdu, China this summer.

With best wishes,

From the President

By Andres Garcia

DEAR SFB COLLEAGUES,

As the summer comes to an end and football season starts (Go, Jackets!), I would like to update you on our progress to date. All committee and task force chairs have been named, and chairs have populated their committees and task forces (thanks to all our volunteers!). Each committee has developed an agenda for the year, and most chairs attended the July Council meeting/strategic planning session. We have instituted monthly progress reports from the committees and task forces to the Board in order to maintain effective communications and integration across all SFB activities.

As I have discussed before, my vision is for our Society to be a thriving international community of leaders, researchers, experts, and educators from academia, industry, and government with far-reaching and lasting impact on all aspects of biomaterials science, engineering and policy. Our efforts are focused on three major areas:

- Increase value to members
- Foster scientific excellence and a nurturing environment
- Expand the impact of SFB

The planning for the 2019 Annual Meeting in Seattle is in full force. The theme for this meeting is *The Pinnacle of Biomaterials Innovation and Excellence*. A record 115 session ideas were submitted, and the Program Committee has selected and consolidated ideas for proposed sessions. The call for abstracts will come out later this month, so be prepared to submit! I expect the Seattle meeting to be a huge success and offer diverse opportunities to our members. In addition to outstanding scientific and technical sessions, professional development and networking opportunities are being developed and incorporated to increase value to our members. The evolving meeting website can be found at https://2019.biomaterials.org.

SFB is a nurturing community, and a major tradition of our society is the awards recognizing the exceptional scientific, professional and service contributions of our members. Awards recognizing excellence for all professional stages, including the new mid-career award, are offered. Please consider nominating your colleagues or trainees. The deadline is September 14, and more information can be found at https://www.biomaterials.org/awards/awards-descriptions.

A point of emphasis for this year is to increase SFB's presence in social media to foster communication and networking among members and disseminate the broad impact and contributions of our Society. The Social Media Task Force is increasing social media presence, and we have now posted tutorials on basic social media communications on the SFB website for Facebook and Twitter. I encourage you to follow us at @SFBiomaterials.

SFB IS A NURTURING COMMUNITY, AND A MAJOR TRADITION OF OUR SOCIETY IS THE AWARDS RECOGNIZING THE EXCEPTIONAL SCIENTIFIC, PROFESSIONAL AND SERVICE CONTRIBUTIONS OF OUR MEMBERS.

In closing, our Society is a thriving and nurturing community at the forefront of scientific excellence and societal impact. I challenge and encourage each of you to be engaged in the diverse activities that we support and to continue enhancing and increasing our impact. I welcome your ideas, suggestions and criticism — please email me at andres.garcia@me.gatech.edu.

Historical Flashback

Professor Tom Horbett, University of Washington

Editor's Notes: *For this issue's "Historical Flashback" column, I asked Prof. Emeritus Tom Horbett (pictured right) of The University of Washington to share with us his early experience with biomaterials science and the SFB. Prof. Horbett is a Fellow of the American Institute for Medical and Biological Engineering and World Biomaterials Congress and a member of SFB and the American Association for the Advancement of Science. He served as the SFB Membership chairman for several years and was the recipient of the 1989 Clemson Award for Basic Research and the 2018 Founders Award. Horbett was trained as a biochemist but collaborated closely with engineers (Hoffman) and polymer chemists (Ratner) as well as pathologist (Lagunoff) and hematologists (Schmer, Harker) to advance the biomaterials field. Horbett also began his faculty career in biomaterials without any startup package but was fortunate to receive generous grant funding from the National Heart, Lung, and Blood Institute (NHLBI) that was sufficient to buy the basic equipment and supplies and to hire technicians needed in his lab. Below is the flashback in his own words.*

INTRODUCTION

A short overview of my earlier days as a biomaterials scientist/engineer, which began in 1971, is provided. I will describe how I got into biomaterials and what the field was like at that time, including the science/engineering, the meetings, and the leaders who influenced me and others at that time. A large part of my group's scientific contributions, those focused on fibrinogen adsorption to biomaterials, were reviewed recently.[1]

MY ENTRY INTO BIOMATERIALS SCIENCE

I received my PhD in biochemistry at the University of Washington (UW) in 1970. I then was going to become a postdoc researcher for Edwin Krebs, a former professor in my UW biochemistry department who had become the chair in Biochemistry at the University of California Davis. Interestingly, Krebs subsequently shared the Nobel Prize in medicine with Edmond Fischer, also of UW. But, as I sat writing my acceptance of the postdoc offer from Krebs, Allan Hoffman asked me to meet with him, as he needed a physical biochemist to help his work on radiation-grafted hydrogels for biomaterials application. Hoffman was then a new professor in Chemical Engineering and the Bioengineering Center. My Biochemistry department chair, Hans Neurath, had recommended me to Allan, whom he met via the Battelle Institute in Seattle. Battelle in those days was cash rich because of their perfection of xerography, and they used some of their funds to support scholars in residence at the institute in Seattle, like Hoffman. Battelle also played an important role because Bob Leininger, a leading chemist at Battelle, encouraged me and Allan to focus

Tom Horbett was working on a spinning disc apparatus to determine critical shear stress for cell detachment.

on protein adsorption to biomaterials, which we did. I told Allan I would think about his offer, but he soon called me back, and I decided to accept his offer.

SUBSEQUENT EVENTS

About a year later, Buddy Ratner joined as the second postdoc in Hoffman's group, and the three of us then worked as the leaders in biomaterials at UW for the rest of our careers, and Buddy Ratner and I were eventually appointed to the regular faculty ranks. Over the many years, great improvements have occurred in biomaterials science and the institutions that support this field, including the Society For Biomaterials, the National Institutes of Health, the National Science Foundation, and our university and its Bioengineering and Chemical Engineering departments, so it has been a great pleasure to be a part of this history. Of course, all this progress is due to devotion and skill and growth of the many people involved.

MENTORS AND OTHERS WHO INFLUENCED MY EARLY CAREER

Hoffman was my direct advisor and mentor when I joined biomaterials, but I was also influenced by other leaders in the field (especially Bob Baier, Ed Leonard, Sung Wan Kim, John Brash, Stuart Cooper, Bruce Morrissey, Leo Vroman and James Anderson), many of whom worked on or shared my interest in

protein adsorption to biomaterials and the field of biomaterials science. I also got to know Bob Langer early in my career, and I still remember his clear statement to me of his decision to NOT do basic research, but instead to apply his engineering skills to perfect novel materials for use in the body — this was my first direct knowledge of what a bioengineer is versus the scientist I was. I read all their newer papers as well as some of their earlier works, listened to their talks and took the opportunity to interact with them in person at national meetings.

Lastly, I was fortunate to have the help of Prof. David Lagunoff of the Pathology department at UW. Lagunoff helped me perform my first soft tissue studies in mice and develop my first grant application, which he kindly read and was an investigator on. Later, Dennis Coleman of the University of Utah and I did a more complete study of the foreign body reactions to biomaterials in rats, focusing on the role of adsorbed proteins. His advisor, Joe Andrade, also had a major impact on our early work via the use of his advanced surface science equipment (electron spectroscopy for chemical analysis/X-ray photoelectron spectroscopy) and his own studies of protein adsorption with *in situ* fluorescence equipment.

EARLY MEETINGS I ATTENDED

A nice historical flashback for me was remembering my first national meeting related to the biomaterials field. I attended the American Society for Artificial Internal Organs meeting in Seattle in the early 70s, where I listened to outstanding talks by Ed Leonard and other leaders in the field and got to know some of these people at brief meetings with them. Hoffman presented a paper at this meeting and got an enthusiastic response to his work with Gottfried Schmer on enzymes immobilized to hydrogels. I did not present my work there. I do recall that Hoffman and others at the meeting were quite excited and enthusiastic and very serious about their work on biomaterials — a nice inspiration for me.

The most important meeting to me at the start of my career was the NHLBI-sponsored contractors meeting. At that time, the NHLBI was funding contract research at many companies to develop better cardiovascular devices and biomaterials, including the total artificial heart and other cardiovascular assist devices like the oxygenators and pumps used during open heart surgery. I learned that the device companies' engineers were well aware that more biocompatible biomaterials were needed but still devoted much more effort to other aspects such as perfecting small pumps that could be implanted and powered externally and had pump chambers that would not break after many millions of flexes that a pump bladder would undergo. The companies did that because they knew they could make progress on hardware design and development but had no clue as to what material properties might lead to more blood compatibility. Another early meeting was the New York Academy of Sciences meeting organized by Vroman and Leonard. This meeting was very large and well attended, with participants from many disciplines represented. As I recall, this meeting was the one at which a movie scene of a whale being implanted with an artificial heart was played during our luncheon, courtesy of the ever-eccentric Vroman, who somehow got the clip made by some Hollywood friends.

The Gordon Research Conference on Biomaterials was also an important venue for biomaterial scientists when I first joined the field. In those days, the prep school venues in New Hampshire were sometimes tests of one's health due to the lack of air conditioning in either the dorm rooms or meeting rooms but nonetheless were the scene of high-level discussions around the clock. At that time, many attendees were from companies like Ethicon that make materials for patient use, as well as clinicians and academicians. Attendees were likely to see an awful lot of pathology slides of implants, as the state of the art then was simply to make a guess as to a better material and evaluate it *in vivo*, with little or no accounting of the molecular or cell-level processes that led to a particular response. For quite a while, an award was given out for the toughest questioner during the conference, the so-called Jaws Award (a large pike with its head propped open to display its fearsome teeth), not infrequently won by Jim Anderson. Another unique memory for me is Leo Vroman's typically unflattering caricature drawings of various attendees. Vroman's caricature of me showed me taking a bath in a tub overflowing with soap bubbles, an allusion from Vroman to the Ivory soap we used to clean Silastic materials we studied, a protocol recommended by the manufacturer, Dow Corning, but suspected by Vroman of leaving behind contaminants. I later suggested naming the Vroman effect after Leo because of his early work on displacement of adsorbed fibrinogen, and when this suggestion was accepted and publicized, Leo decided I was acceptable after all.

The Society For Biomaterials was quite small when I joined the field in 1971, and its dominant focus was on dental biomaterials, so I did not join it until it began to expand to include cardiovascular biomaterials. As I recall, the first SFB meeting I attended was held in Troy, New York, on the Rensselaer Polytechnic Institute campus and had only a few hundred attendees. For me, it was important because it was then that I realized that I now had a professional home for my work, in the sense of fellow devotees to the science of biomaterials who

Historical Flashback (continued from page 5)

cared a lot about advancing the field and who were interested in biomaterials per se rather than a device that the material might be used in. The focus on biocompatibility and mechanisms thereof was attractive to me.

DEVELOPMENT OF MY INTERESTS AND MY RESEARCH LAB

The first person to receive an artificial heart was Barney Clark, and this also happened early in my biomaterials career. Clark's demise from thromboembolic complications was a case study in the need for more blood-compatible materials and devices. I therefore began to focus less on the foreign body reaction in soft tissue and more on blood compatibility. I soon learned that the field I entered was strongly supported by cardiovascular surgeons such as Henry Edmonds, whom I got to know early on via serving on the bioengineering study section with Edmonds. Edmonds visited Seattle fairly often, as he grew up in Seattle and had relatives here, so I took advantage of the opportunity to talk with him in Seattle. Edmonds and his group did an impressive early study of the clinical utility of so-called end-point immobilized heparin, which had been touted to eliminate the need for heparin administration to the patient's blood, finding it imperfect in preventing clotting. To this day, cardiovascular devices such as stents require the use of regular anticoagulant therapy, but nowadays antiplatelet agents are used.

I also paid a lot of attention to scanning calorimetric studies of protein adsorption done by Emery Nyilas and others. In those early days, many investigations of protein adsorption were done using physical methods like calorimetry or *in situ* Fourier-transform infrared spectroscopy or fluorescence spectroscopy, usually with single-protein solutions. I started measurements of protein adsorption using a colorimetric method on base hydrolysates of the adsorbed proteins (the ninhydrin assay), a method that worked but was not so easy to do correctly and also had marginal sensitivity. I soon decided to develop methods more suited to adsorption from mixtures like blood plasma, and much of my subsequent work with I-125 radiolabeled proteins benefited greatly from the large commitment involved in the use of radiotracer technology. Radiotracer technology requires learning to run a lab with proper radiotracer safety protocols, often with largely untrained and sometimes uncooperative or uncaring personnel. (I soon learned to get tough with folks, as needed. I also should have got tough with my university, who neglected to properly supervise and fund the main university radiation safety office, leading to a yearlong shutdown by the state.) I was suited to this approach because I already had a lot of experience making chemical modifications of proteins for my thesis, and my background in physical biochemistry of proteins was also quite helpful, particularly how to ensure a protein prep was pure and stable. I also had some luck in that a manual gamma counter was available in the Chemical Engineering department for me to use. We did have to purchase a survey meter for radiosafety purposes, but they are relatively inexpensive. As indicated already, the main burden is not so much the equipment but rather developing efficient radiosafety procedures. Only a few other labs made the commitment to radiotracer methods — for example, John Brash and his group were about the only others to use this method for protein adsorption studies.

THE FIELD OF BIOMATERIALS WHEN I JOINED

The biomaterials field was still primitive in the sense that none of us considered specific cellular recognition mechanisms based on cellular receptors such as the integrins and their ligands such as fibronectin. The existence and definition of those biochemical processes was just beginning to be worked out by biochemists and had not yet impacted biomaterials science. Instead, our field was still thinking of general chemical mechanisms such as acid/base theory and the van der Waals forces, as represented by Leonard Weiss' ideas on cell interactions. But in fact, bodily reactions to biomaterials involve many specific biochemical events, albeit translated to the situation where they occur at synthetic biomaterial interfaces rather than natural structures such as extracellular matrices. Many of the review articles I have written focus on the biochemistry of cell interactions with biomaterials that are mediated by adhesion receptor interactions with proteins adsorbed to the biomaterials.[2]

A FINAL COMMENT

I have commented on only a few of the experiences I have had as a biomaterials scientist, namely some early highlights of my career. Over all the years of my career, I of course attended many more meetings than those mentioned above and met many other people who affected my career and contributed to my lab's research progress, so I want to say thanks to all of them even though I cannot describe them here. Finally, I hope this brief overview of the early days of my biomaterials career properly conveys the generally happy experiences I was lucky to have as a long-time biomaterials scientist and my ongoing appreciation of all the help I had from my colleagues and lab members. I wish the best to my younger colleagues continuing on in the field and look forward to continued great progress in providing ever better biomaterials for mankind.

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2. Horbett TA. The role of adsorbed proteins in tissue response to biomaterials. In: Ratner B, Hoffman AS, Schoen F, Lemons E, editors. *Biomaterials Science: An Introduction to Materials in Medicine*. San Diego, CA: Academic Press; 2004. p 237-246.

Member News

By Rebecca Carrier, Member-at-Large

Society For Biomaterials members, I am honored to serve as your 2018-2019 Member-at-Large. I aim to work with you to give SFB membership a clear voice for SFB's direction, so together we can help SFB grow and maximize the value of your SFB membership — please email me at r.carrier@northeastern.edu with any ideas and feedback you would like to share!

This quarter's exciting member news and accomplishments include the following:

Özgül Gök, assistant professor at the Department of Medical Engineering at Acıbadem Mehmet Ali Aydinlar University, recently organized a 3D bioprinting workshop together with the company AxolotlBio at the Acıbadem University Incubation Center, July 11, 2018. Her talk, entitled "Replaceable You," covered the choice of bioinks, the preparation of biomaterials as multifunctional smart polymeric biomaterials and various strategies for their fabrication in the tissue engineering field. Attending researchers learned about bioprinting instrumentation and working principles as introduced by AxolotlBio management and also had the opportunity to practice printing different materials like alginate and gelatin methacryloyl in the laboratories. A major focus of this 3D bioprinting workshop was to stimulate interdisciplinary research among chemists, biologists, electronics and clinicians in a health-focused university.

Prof. **Chris Jewell**, associate professor and associate chair for research in the Fischell Department of Bioengineering at the University of Maryland, received the 2018 Owens Corning Early Career Award and the 2018 Nanoscale Science and Engineering Forum (NSEF) Young Investigator Award, both from the American Institute of Chemical Engineers. The NSEF Young Investigator Award recognizes outstanding scholarship, commercialization, education or service in nanoscience and nanotechnology demonstrated by engineers or scientists in the early stages of their professional careers. The Owens Corning Early Career Award is for faculty members under 40 years of age demonstrating outstanding independent contributions to the scientific, technological, educational or service areas of materials science and engineering for a faculty.

Dr. Jewell's lab brings together engineering and immunology to fight disease, working in vaccine design and immunotherapy, biomaterial interactions with the immune system and autoimmunity.

Jeff Karp, associate professor at Brigham and Women's Hospital (BWH), Harvard Medical School, and principal faculty at the Harvard Stem Cell Institute, recently published work aimed at developing "surgery in a pill" technology as a potential treatment for diabetes. Gastric bypass surgery has been found to reverse type 2 diabetes but is associated with disadvantages including invasiveness and cost of surgery. The team of researchers Dr. Karp is working with, including Ali Tavakkoli, MD, codirector of the Center for Weight Management and Metabolic Surgery at BWH, is developing a pill that coats the lining of the intestine and gut, replicating the effects of gastric bypass without the invasiveness or cost of surgery. The team recently published an article in *Nature Materials* reporting results of a preclinical study in which rats were orally dosed with an agent designed to coat the intestine and prevent nutrient contact with the proximal bowel to avoid post-meal spikes in blood sugar. For more information, see sciencedaily.com/releases/2018/06/180611133755.htm.

SFB's Orthopedic Biomaterials SIG chair, **Bingyun Li (professor at the West Virginia University Health Sciences Center)** and SFB's past-president and current board member, **Thomas J. Webster** (professor and chair of chemical engineering, Northeastern University) have coedited two books on orthopedic biomaterials. These two books were published by Springer International Publishing in March and August 2018 and are among only a few books to include contributions from clinicians, industry and academia to provide a truly comprehensive look at biomaterials and bone implants. These books highlight the recent advances in orthopedic biomaterials, including reducing infection, developing *in situ* sensors, and promoting bone growth, nanotechnology, polymers and biomimetics.

Nicholas A. Peppas, professor of biomedical engineering, chemical engineering, pediatrics, surgery and pharmacy at the University of Texas at Austin, was elected and inducted as a foreign member to the Chinese Academy of Engineering (CAE). Membership in the CAE is the highest engineering distinction in China, and CAE represents one of the most prestigious engineering communities in the world. Dr. Peppas was elected to the CAE based on his seminal contributions to biomaterials, drug delivery and chemical engineering. He presented an inaugural lecture at the CAE. Dr. Peppas was also appointed as an honorary professor of Beihang University. These honors reflect the tremendous significance of Dr. Peppas' accomplishments as a professor, researcher, and entrepreneur in biomaterials and drug delivery. He has 45 U.S. patents pending

[CONTINUED ON PAGE 8]

or issued, three companies founded, more than 1,650 papers published with 105,000 citations, and numerous honors reflecting the impact of his contributions, including being a member of three national academies in the U.S.: the National Academy of Medicine, the National Academy of Engineering and the National Academy of Inventors. For more information, see engr.utexas.edu/news/8283-peppas-cae and ev.buaa.edu.cn/info/1013/1615.htm.

David Puleo, associate dean for research and graduate studies in the University of Kentucky (UK) College of Engineering, has been named dean of the University of Mississippi School of Engineering. He began his duties August 27. Dr. Puleo joined UK in 1991 after receiving his PhD in biomedical engineering from Rensselaer Polytechnic Institute in Troy, New York. He became director of the Center for Biomedical Engineering (now the F. Joseph Halcomb III, M.D. Department of Biomedical Engineering) in 2005 and associate dean for research and graduate studies in 2015.

Thomas Webster, together with postdoctoral researcher Andrew Jones and graduate student Gujie Mi, recently published an article describing the innovation ecosystem necessary for implementing nanostructured materials in biomedical devices. The article, entitled "A Status Report on FDA Approval of Medical Devices Containing Nanostructured Materials," discusses the slow commercialization since the FDA approved a medical device containing nanomaterials in 1980. The article highlights the significance of geographical and structural separation of researchers, manufacturers and clinical servicers in slowing commercialization, more than FDA approval. For more information, see doi.org/10.1016/j.tibtech.2018.06.003.

Georgia Institute of Technology recently received a new five-year grant from the National Institutes of Health (NIH) to train the next generation of leaders in ImmunoEngineering – a new wave of researchers applying the tools and principles of engineering to study the immune system in health and disease in the quest for breakthrough solutions to improve the lives of patients. The NIH T32 grant, is entitled "Research Training Program in ImmunoEngineering." The five trainees selected for 2017-2018 are **Nicholas Beskid** (from Babensee's lab), **David Francis** (from the lab of Susan Thomas), **Midori Maeda** (from the lab of Shuichi Takayama), **Katily Ramirez** (from the lab of Todd Sulcheck), **Cory Sago** (from the lab of James Dahlman). Another trainee, **Jeff Noble** (from the lab of M.G. Finn) deferred to 2018-2019. The training program is directed by **Julia Babensee**, along with two co-directors, **Susan Thomas** and **Rafi Ahmed**.

ATTENTION MEMBERS!

WE WOULD LOVE TO HEAR FROM YOU.

IF YOU HAVE NEWS TO SHARE WITH FORUM READERS, LET US KNOW. EMAIL YOUR NEWS AND ANY PHOTOS TO R.CARRIER@NORTHEASTERN.EDU AND YOU COULD BE FEATURED IN THE NEXT ISSUE.

Staff Update

By Pam Gleason, Assistant Executive Director

Hello from Society For Biomaterials headquarters! SFB's governing Council held a strategic planning meeting on July 19, 2018. As the new program year gets underway, the Society's Board of Directors, governing Council, committees, task forces and Special Interest Groups (SIGs) will be working to advance the Society's strategic plan. (A PowerPoint summary of the Strategic Plan is available under the About menu of the website.)

AWARDS, CEREMONIES AND NOMINATIONS COMMITTEE

Chair: Thomas Webster, PhD

The Committee solicited nominations for 2019. Award nominations closed on September 14, 2018, and officer nominations closed on September 21, 2018. Award nominations are currently under review for announcement of selected recipients to be made in late November. Officer nominations, once formalized by the Committee, will be forwarded to the Council for ratification and election to be held in early 2019.

BYLAWS

Chair: Ben Keselowsky, PhD

The Committee will be reviewing the bylaws and discussing any possible amendments.

EDUCATION AND PROFESSIONAL DEVELOPMENT

Chair: Jan Stegemann, PhD

The Committee will be reviewing submissions for 2019 Biomaterials Days Grants. The applications were due by September 14, 2018, and funding will be announced in November.

FINANCE

Chair: Elizabeth Cosgriff-Hernandez, PhD

The Society is in line with income and expense projections and has a positive operational net income. The Finance Committee is recommending to the Board that transfers be made to bring the Society back to its chartered fund distributions. SFB is preparing the 2019 budget for continued growth. Please continue your support by booking your accommodations for the 2019 Annual Meeting at the headquarters hotel.

INDUSTRIAL AFFAIRS

Chair: Peter Edelman, PhD

The Committee will be reviewing matters of particular concern to the manufacture of biomaterials and developing content for the Annual Meeting Program as directed and requested by the Program Committee.

LIAISON

Chair: Tim Topoleski, PhD

The Committee is finalizing plans for a 2020 Fall Symposium with the Japanese Society For Biomaterials to be held in Honolulu, Hawaii, December 13-15, 2020.

MEMBERSHIP

Chair: Anirban Sen Gupta, PhD

Current membership stands at 1,361, which continues to trend upward; this time last year, we were at 1,161, and at 1,055 in 2016. The Committee continues to develop strategies to increase membership, especially focusing on industry and clinical sectors.

PROGRAM

Co-Chairs: Gopinath Mani, PhD and William Murphy, PhD

The 2019 Society For Biomaterials Annual Meeting and Exposition will take place in Seattle, Washington, April 2-6, 2019. The call for abstracts will be distributed, and the 2019 website and abstract submission portal is now open. Again this year, the Society will charge $25 per abstract submission before the October 24th deadline. Abstracts submitted between October 25th and November 7th will be subject to a $50 submission fee.

SPECIAL INTEREST GROUPS

Representative: Sarah Stabenfeldt, PhD

The SIGs have submitted proposals for the 2019 meeting in Seattle and planned their budgets for 2019. The publication of the *SIGnal* newsletter continues on a monthly basis.

If you have any questions,

need any information or have suggestions for improved services, please feel free to contact the Society's Headquarters office:

SOCIETY FOR BIOMATERIALS
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Phone: 856-439-0826 • Fax: 856-439-0525
Email: info@biomaterials.org • URL: biomaterials.org

2018 Biomaterials Education Challenge

The Biomaterials Education Challenge encourages and challenges Society For Biomaterials student chapters and other student clubs or groups to develop innovative and practical approaches to biomaterials education for middle school (sixth through eighth grade) science classes. Teams are challenged to develop an educational module that will both improve widespread understanding of biomaterials-related science and expose students to potential career opportunities. Modules are expected to be engaging, hands-on learning experiences that demonstrate fundamental biomaterials concepts and can be easily completed within a 45-minute class period; learning objectives should be clearly understood and materials easily obtained.

Winners will have emphasized innovation, practicality, and the likelihood of widespread adoption and dissemination, through demonstration of educational impact. Finalists are selected based on the submitted abstracts to present a poster to the panel of judges.

This year's Biomaterials Education Challenge was held at SFB's 2018 Annual Meeting & Exposition in Atlanta, Georgia. The following are the results of the challenge:

First Place: Texas A & M University, College Station, Texas
Second Place: University of Florida, Gainesville, Florida
Third Place: Case Western Reserve University, Cleveland, Ohio

Judges: Dr. Bill Murphy, Dr. Elizabeth Cosgriff-Hernandez, Dr. Chris Bettinger and Dr. Anirban Sen Gupta.

Gathering for LGBTQI and Friends

The first SFB Lesbian-Gay-Bisexual-Transgender-Queer-Intersex (LGBTQI) and friends event was held during the 2018 Annual Meeting in Altanta, Georgia. Over 60 people attended the event representing members of the society, students and meeting attendees. The informal event was hosted by Joel D. Bumgardner (The University of Memphis, SFB past-president), Elizabeth Cosgriff-Hernandez (The University of Texas Austin, SFB secretary-treasurer-elect) and Marvin Mecwan (University of Washington, graduate student). Everyone attending was enthusiastic to support LGBTQI individuals in the biomaterials community and to have opportunities to develop new professional and personal network connections. Attendees also commented that it was a great time to unwind, relax and have some fun after a packed day of meeting sessions. There was also much enthusiasm expressed to continue the gatherings for LGBTQI and friends, and plans are in progress to hold the event again during the 2019 SFB Annual Meeting in Seattle. Individuals interested in participating or helping to organize the LGBTQI and friends gathering should contact Joel D. Bumgardner. The hosts and those attending the gathering would also like to thank Dan Lemyre and his staff and SFB leadership for supporting and helping to promote the first LGBTQI gathering by sending out text messages and emails and posting fliers during the 2018 Annual Meeting. We're looking forward to another great LGBTQI and friends event at the 2019 Annual Meeting.

EVERYONE ATTENDING WAS ENTHUSIASTIC TO SUPPORT LGBTQI INDIVIDUALS IN THE BIOMATERIALS COMMUNITY AND TO HAVE OPPORTUNITIES TO DEVELOP NEW PROFESSIONAL AND PERSONAL NETWORK CONNECTIONS.

Update from the Cardiovascular Biomaterials SIG

STEM CELL THERAPIES FOR PERIPHERAL ARTERIAL DISEASE: CLINICAL STATUS, PROMISING BIOMATERIALS STRATEGIES AND TIPS FOR SUCCESSFUL TRANSLATION

By Ngan F. Huang Stanford Cardiovascular Institute, Stanford University, Stanford, California, USA and Michael Naimarkand Rami Tzafriri, CBSET, Departments of Business Development and Research and Innovations, Lexington, Massachussetts, USA

INTRODUCTION

An estimated 202 million adults worldwide are affected by peripheral artery disease (PAD),[1] which is caused by the accumulation of plaque in peripheral arteries (commonly the pelvis or leg) reducing blood flow and tissue oxygenation. Left untreated, PAD can lead to severe pain, immobility, nonhealing wounds and eventually limb amputation. With risk factors such as diabetes and obesity on the rise, the prevalence of PAD is growing at double-digit rates. Current treatments such as angioplasty or bypass surgery target the primary occluded macro vessel and fail to reverse or treat the surrounding microvasculature, often leading to irreversible tissue loss and potential limb amputation.

Cell transplantation into the ischemic tissue is being studied as a therapeutic strategy to re-establish functional collateral networks that supply oxygenated blood and preserve tissue viability.[2] For treatment of cardiovascular diseases alone, there are currently multiple clinical trials involving injection of stem cells into ischemic tissues. For individuals who have peripheral arterial disease who receive stem cell therapy, the evidence includes small randomized trials and systematic reviews. Relevant outcomes are overall survival, symptoms, change in disease status, morbid events, functional outcomes, quality of life, and treatment-related morbidity. A meta-analysis of these trials with the lowest risk of bias has shown no significant benefit of stem cell therapy for overall survival, amputation-free survival or amputation rates.[3] Well-designed randomized controlled trials with a larger number of subjects and low risk of bias are needed to evaluate the health outcomes of these various procedures, as well as their durability. Several are in progress, including multicenter randomized, double-blind, placebo-controlled trials.[4]

While the clinical picture is evolving, evidence from preclinical studies indicates that ***cell viability is typically only 5%,*** suggesting that therapeutic success critically hinges on the survival and subsequent maintenance of the transplanted cells.[2] Therefore, new methods to protect the cells during and after injection are needed.

PROTEIN-ENGINEERED HYDROGELS FOR ENHANCED SURVIVAL OF INDUCED PLURIPOTENT STEM CELL-DERIVED ENDOTHELIAL CELLS

Rufaihah and colleagues previously showed that the injection of human induced pluripotent stem cell-derived endothelial cells (hiPSC-ECs) to the ischemic murine hindlimb, as an experimental model of PAD, improved blood perfusion and promoted neovascularization. However, based on noninvasive molecular imaging, cell survival rapidly declined over time after injection into the ischemic muscle in saline.[5]

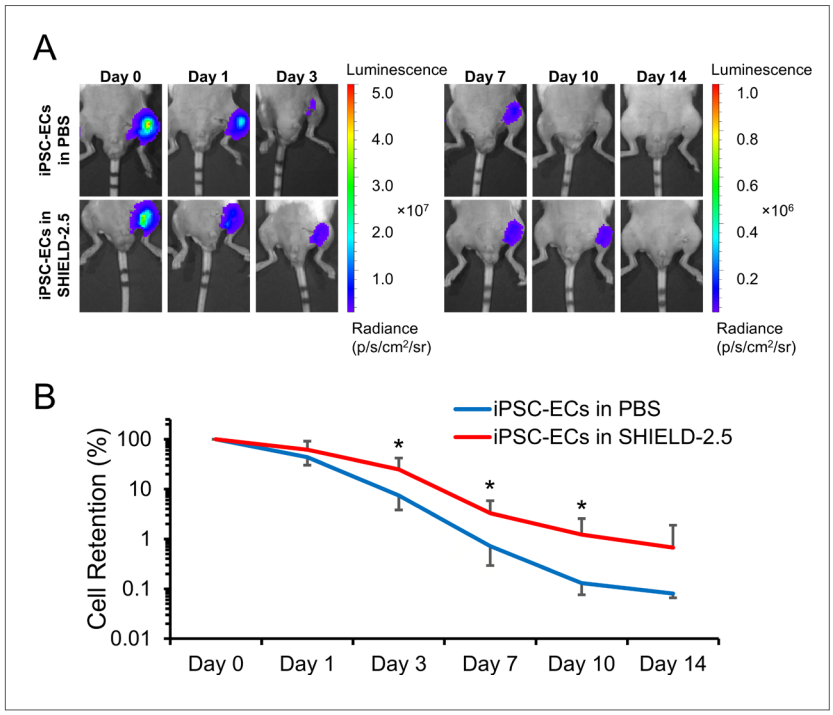
To overcome the limitation of transplanted cell death, the Huang and Heilshorn laboratories are designing injectable material to improve cell viability and promote greater therapeutic neovascularization after a single administration of iPSC-ECs. Such materials are defined as injectable hydrogels that (i) provide protection from the mechanically disruptive forces experienced during syringe-needle flow; (ii) enable cell proliferation and spreading; (iii) are biodegradable and biocompatible; and (iv) have controllable mechanical stiffness. These properties mechanically shield the cells from shear forces during injection and provide ideal cell-adhesive matrix ligands, material stiffness and soluble cues to promote cell survival after injection.

The Huang and Heilshorn laboratories developed protein-based hydrogels called SHIELD (shear-thinning hydrogel for injectable encapsulation and long-term delivery) for co-transplantation of hiPSC-ECs into the site of tissue ischemia.[6] *In vitro* studies under hypoxic conditions (1% O2) demonstrated improved acute viability and proliferation of iPSC-ECs following syringe injection delivery in SHIELD with a 400 Pa storage modulus, compared to saline. When hiPSC-ECs were encapsulated within SHIELD at the time of injection into the ischemic limbs of immunodeficient mice, the cells showed significantly higher viability over the course of 14 days, when compared to cells delivered in saline (**Figure 1**). Furthermore, histological analysis demonstrated significantly improved arteriogenesis in the ischemic limb muscle upon treatment of hiPSC-ECs encapsulated within SHIELD, compared to cells delivered in saline alone. This preclinical study demonstrates the safety and feasibility of employing shear-thinning hydrogels to enhance the survival and efficacy of therapeutic cells in the setting of limb ischemia.

(A) iPSC-ECs were delivered in PBS or SHIELD-2.5 by intramuscular injection of the ischemic limb and were tracked noninvasively by bioluminescence imaging for up to 14 days. (B) Percentage of injected cells retained in the ischemic limb. *$P < 0.05$, $n = 7$ (iPSC-ECs in PBS), $n = 9$ (iPSC-ECs in SHIELD-2.5). Reprinted with permission from Foster *et al.*[6]

[CONTINUED ON PAGE 12]

Figure 1



Localization and survival of iPSC-ECs in the ischemic limb.

KEYS TO SUCCESSFUL TRANSLATION

Fueled by exciting research developments like the one described above, stem cell and gene therapy have the potential to provide efficacious treatments of PAD and other elusive diseases. By functioning as biological test articles, stem cells and gene therapy offer the sophisticated molecular mechanisms of healthy physiology to address dysfunction and pathology in a more comprehensive and dynamic manner than has ever been available before. However, the same scientific potential and complexity that make these therapies so promising create a host of new concerns when it comes to U.S. Food and Drug Administration (FDA) review and approval. Understanding how the regulatory pathway may differ for these novel therapies is a key component of designing a successful translational project and setting realistic timelines and milestones for your program.[7]

As FDA reviews can be complex and confusing, even for seasoned investigators, preclinical program managers should look for every opportunity to gain feedback and receive comments from the agency. One of the unique opportunities available to your translational biologic, gene therapy or cell-based program is a mechanism available through the Center for Biologics, Evaluation and Research/Office of Tissues and Advanced Therapies offices — literally a pre-, pre-IND meeting, formally designated as a "Type C" meeting, to give the agency an opportunity to unofficially review where you are and where you plan to go next, in advance of the formal "Type-B" pre-IND meeting. The meeting is informal, generates no agency minutes, and can be invaluable in planning your project development milestones well in advance.

Any good preclinical program should include realistic assessments of what capabilities need to be outsourced to qualified and credible partners, and this should occur very early in your program planning. Because the two key areas of a regulatory submission are preclinical safety data and the process used to manufacture and prepare the test article for clinical use, screening for your ideal contract manufacturing organization (CMO) and preclinical contract research organization (CRO) partners early in your project roadmap is absolutely critical to de-risking your program and your early interactions with the FDA. Your CMO and CRO teams should be able to bring valuable experience when operating within the FDA's regulatory structure and can help ensure that your developmental milestones are realistic and appropriate based on their specific scientific and regulatory experience.

Representatives from your cGMP CMO and preclinical CRO should be involved in your preparations for the earliest possible interaction with the agency to help refine your approaches, anticipate issues and offer justifications of your choices. An experienced regulatory compliance consultant with knowledge of the FDA's evolving approaches to cell-based therapies is always a welcome participant and strengthens your position entering into your interactions with the agency by properly interpreting the written and spoken feedback you will get before, during and following these meetings.

Getting revolutionary therapies to the clinic takes more than groundbreaking science. The journey to a successful submission should be viewed as a synergetic process, and in many cases the best and most successful approach will require a consortium of experienced collaborators to address the specific complexities of your program. Proper planning and preparation in advance of your FDA interactions will allow the agency's scrutiny to focus on the key to your success — your science.

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Update from the Immunoengineering SIG

NATIONAL INSTITUTE OF BIOMEDICAL IMAGING AND BIOENGINEERING IMMUNOENGINEERING ROUNDTABLE DISCUSSION AT SFB

By Yaoying Wu, Postdoc, Duke University

As research focusing on the intersection of immunology and biomaterials is gradually intensifying, there is an ever-growing demand for a funding mechanism to support this field. To better understand the needs and challenges of researchers, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) sponsored a stimulating roundtable discussion at the SFB 2018 Annual Meeting in Atlanta, Georgia. The session began with broad overview presentations of current developments in several important research directions, such as wound healing, multiple sclerosis and cancer, shared by a few of the leading scientists in the field of immunoengineering, including Profs. Jennifer Elisseeff, Christopher Jewell and Jonathan Schneck from John Hopkins University; Prof. Joel Collier from Duke University; and Prof. David Mooney from Harvard University. NIBIB program officers introduced the newly established immunoengineering program and especially proposed to assemble a new study session focusing on biomaterials immunomodulation. This proposal was met with great enthusiasm in the room and ignited lively discussion for a better way to build a review panel that can better serve the research community and bridge the gap between biomaterials and immunology. The roundtable discussion concluded with small group discussions for NIBIB to elicit suggestions and concerns that audiences might have. We think this roundtable was an extremely encouraging sign for researchers interested in immunoengineering. It indicates that the significance of the research is being recognized broadly, both by the funding agency and by scientific communities, and tangible research supports are rolling into action from the funding agencies, with the National Institutes of Health playing a leading role.

RESEARCH HIGHLIGHTS

The macrophage is one of the most important cells in human innate immune systems, and it plays a vital role in wound healing, clearing foreign substances, cancer cells, etc. However, a tumor-immune microenvironment predominantly promotes tumor-associated macrophages (TAM). Although M1 subtype macrophages are proinflammatory and provide antitumor immunity, TAMs are primarily found to be tumor-promoting and anti-inflammatory (M2 subtype), which facilitate tumor angiogenesis and metastasis. Clinically, TAMs have been associated with poor prognosis and have profound impact in regulating tumor progression. Hence, targeting TAMs could be one promising strategy for cancer treatment. To achieve this goal, two research teams published their novel platforms in polarizing macrophages toward M1-like tumor-killing subtype. Rodell and colleagues used a novel morphometric polarization screening technology to evaluate 38 drugs for their macrophage polarizing ability and identified R848 (resiquimod), a toll-like receptor 7/8 agonist. The R848 drug was loaded into cyclodextrin-based nanoparticles (CDNPs) as a hydrophobic gets encapsulated in cyclodextrin's cavities. R848-loaded CDNPs were shown to significantly promote M1 macrophage polarization in IL-12 reporter mice, as compared to R848 by itself. Furthermore, drug-loaded CDNPs improved the survival of tumor-bearing mice. With the synergistic effect from PD-1 blockade therapy, the combinatory treatment strategy greatly enhanced the antitumor activity of CDNP-R848 in both the colorectal cancer model and melanoma.

In another independent study, Kulkarni and colleagues developed nanoparticles that can codeliver CSF-1R inhibitor (BLZ945) and CD47 blockade antibody for enhanced macrophage phagocytosis of cancer cells. It has been shown that blocking the CSF-1R receptor could deplete M2-like TAMs. The authors suspected that, by inhibiting the CD47 (don't eat me) signal, these nanoparticles could reprogram an M2-like phenotype to an M1-like phenotype. Through computation, the authors designed a lipid-based nanoparticle AK750 with improved loading of BLZ945 (~20%). AK750 was shown to be effective in inhibiting CSF-1R in *in vitro* experiments. Notably, with signal-regulatory protein alpha (SIRPα)-CD47 blockade antibodies, AK750 increased the efficiency of the drug and achieved macrophage M1 polarization at the early timepoint. And a single dose of anti-SIRPα-AK750 significantly inhibits melanoma growth *in vivo*.

Both macrophage-targeting therapeutics are exciting additions to cancer immunotherapies, highlighting the efficacy of TAM-targeting therapy. They also provided researchers the possibilities to encapsulate other various immunomodulatory drugs in other platforms.

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Industry News

By Steve Lin, Industry News Editor

The House voted to repeal a 2.3 percent excise tax on medical devices, again showing bipartisan support for eliminating the levy. Congress created the tax in the 2010 Affordable Care Act to help pay for expanding health insurance, but medical-device companies and their home-state allies in both parties have been fighting against it ever since. The tax took effect in 2013, but Congress suspended it starting in 2016 and recently extended that moratorium until January 2020. The tax applies to products such as pacemakers and artificial joints, not items directly sold to consumers.

Genentech, a member of the Roche Group, announced positive top-line results from the Phase II LADDER study evaluating the efficacy and safety of its investigational port delivery system (PDS) with ranibizumab in people with wet age-related macular degeneration (AMD), a leading cause of blindness for people age 60 and over, in the United States. The small, refillable eye implant, which is slightly longer than a grain of rice, is designed to allow people with wet AMD to go several months without needing to visit their ophthalmologist for treatment. The majority of PDS patients enrolled in the LADDER trial went six months or longer between implant of the device and the first required refill. Vision outcomes in the high-dose PDS group were similar to monthly ranibizumab eye injections and were maintained throughout the study period.

MiMedx Group, Inc., the maker of surgical and tissue graft products, announced the appointment of Mark Graves to the position of chief compliance officer to strengthen its corporate compliance practices. "We are implementing plans to improve our corporate compliance practices in order to ensure our company adheres to policies with the highest integrity, ethics and legal standards," said David Coles, interim CEO of MiMedx. Earlier this month, Parker "Pete" Petit resigned from the posts of chairman and chief executive officer, and William "Bill" Taylor resigned as president and chief operating officer amid an ongoing investigation of the company's accounting practices. In June, Michael Senker had quit as chief financial officer, along with corporate controller and treasurer John Cranston. The Audit Committee has already concluded that MiMedx's financial statements from fiscal year 2012 need to be restated.

The U.S. Food and Drug Administration (FDA) was notified by Bayer that the Essure permanent birth control device will no longer be sold or distributed after December 31, 2018. This decision follows the FDA's patient safety action in April, in which the agency issued an order restricting the sale and distribution of Essure; it was a unique type of restriction where the FDA used its authority to impose additional requirements to provide a reasonable assurance of the device's safety and effectiveness. The decision to halt Essure sales also follows a series of earlier actions that the FDA took to address the reports of serious adverse events associated with its use.

ReWalk Robotics, Ltd. announced that the U.S. Department of Veterans Affairs (VA) has issued a revision to its national policy on exoskeleton medical device training and procurement for qualifying veterans with spinal cord injury. The updated policy includes further guidance on the evaluation process and expands access to training program locations among the VA network and private rehabilitation centers through the VA's Veterans Choice Program. The evaluation process will now have all veterans flow through one of 24 designated spinal cord injury VA centers. Once a veteran is determined to be qualified for training and procurement of his or her own exoskeleton system, the individual may be allowed to pursue training.

Insight Medical Systems has teamed up with **Onkos Surgical, Inc.** to explore opportunities to apply Insight Medical's Augmented Reality Visualization and Information System (ARVIS™) in musculoskeletal oncology. The companies are working on a pilot project to assess the technology for use in tumor surgery. ARVIS™ has tracking and visualization capabilities that allow precise and efficient execution of surgical plans. The headset has the ability to project virtual models of the patient's anatomy into the surgeon's field of view during the surgical procedure so that anatomical structures beneath the surface are visible. Similarly, virtual models of the implants or instruments are projected so that the surgeon can see his or her relationship to the hidden anatomical structures. Key measurements such as the orientation and position of instruments and implants relative to the patient's anatomy are displayed. This may enable less invasive surgery, improve outcomes and reduce patient risk.

DRMC X-Ray, Inc. ("DRMC"), an affiliate of Faxitron, was formed to take title to Faxitron's irradiation assets and announced the acquisition of the assets of **Precision X-ray Inc.** (PXi). Both Faxitron and PXi have deep roots in cabinet X-ray for biological irradiation. Under DRMC, this new combination will leverage the research and development (R&D) strength and pedigree of PXi with Faxitron's focus on integration and automation. Corporate

headquarters, R&D and manufacturing operations will be located in North Branford, Connecticut, the current home of PXi. DRMC will continue to operate under the PXi name. The combined company has an enviable global installed base in excess of 1,000 systems and intends to substantially increase investment in all areas of the combined business to rapidly accelerate development and market adoption of its devices.

Mauna Kea Technologies, inventor of Cellvizio®, the multidisciplinary probe-based confocal laser endomicroscopy (pCLE) platform, announced the publication of a prospective multicenter study that demonstrates the potential of Cellvizio to aid in the diagnosis of acute cellular rejection (ACR) in lung transplant patients. ACR in lung transplant recipients is diagnosed by identifying perivascular cellularity (PVC) from alveolar tissue typically obtained via invasive transbronchial biopsies. This study compared *in vivo* real-time histological imaging using Cellvizio for the identification of alveolar, vascular and cellular microstructures of lung transplants to transbronchial biopsies. The prospective multicenter study enrolled 24 patients who had undergone a lung transplant within the prior 12 months and who were scheduled for diagnostic biopsies. The study showed that pCLE identification of PVC is a feasible and reproducible criterion for assessment of acute cellular rejection *in vivo*.

Observations From the Biomaterials Definitions Meeting

By Carl Simon

Fifty-three international delegates convened in Chengdu, China on June 11–12, 2018, for the "Conference on Definitions in Biomaterials." The meeting was held under the auspices of the International Union of Societies for Biomaterials Science and Engineering (IUSBSE), which represents the Australian, Canadian, Chinese, European, Japanese, Korean, Latin American, Indian and U.S. biomaterials societies. A previous Conference on Definitions in Biomaterials was held in Chester, UK, in 1986. Due to the "significant developments in biomaterials science and the diverse applications of biomaterials," these definitions were reconsidered at this consensus conference organized by David Williams (Wake Forest Institute of Regenerative Medicine, USA) and Xingdong Zhang (president IUSBSE, Sichuan University, China). Delegate affiliations were 92 percent academic, 6 percent government, and 2 percent nonprofit. By continent, delegate affiliations were 45 percent Asian, 34 percent North American, 13 percent European, 6 percent Australian and 2 percent African. The meeting was organized into seven sessions. The plenary speaker for each session selected terms for discussion with input from the organizing committee. The terms were distributed to the delegates before the meeting. Each session was two hours, and the proposed definitions were discussed in order of importance as determined by the plenary speaker. The definitions were projected on a screen and edited during the course of discussion. Some terms were discussed but not voted upon due to lack of interest from the delegates or lack of apparent consensus. If, after discussion, it appeared that a consensus could be reached, then delegates made a formal vote. A "Yes" vote indicated that the definition was adequate. A "No" vote indicated that the definition was incorrect. A definition achieved consensus with a vote of 75 percent "Yes." A vote of 50 to 75 percent "Yes" was deemed "Provisional." Approximately 50 definitions reached ballot, including terms such as "biomaterial," "biocompatibility," "hydrogel," "regenerative medicine," and "tissue engineering." The results of the meeting will be published in proceedings in book format.

CONTACT

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Cato T. Laurencin Travel Fellowship Winners

The 2018 Cato T. Laurencin Travel Fellowship recipients are **Mary Omotoso** of North Carolina A&T State University and **Timothy Mason** of the University of Connecticut (see photos of Mary Omotoso and Tim Mason). In response to our request to share with us what receiving this fellowship and attending the SFB Annual Meeting meant to them, Mary Omotoso wrote the following:

As an undergraduate student in the field of biomaterials, I had been advised by two of my mentors to apply for the Cato T. Laurencin Travel Fellowship. I had previously heard Dr. Laurencin speak when I attended the Annual Biomedical Research Conference for Minority Students in Tampa, Florida, and was familiar with his work. Upon finding out that I had been selected for the travel fellowship, I began planning what I would do during my time there. I was very excited. This travel fellowship allowed me to engage with researchers from different backgrounds and showed me how committed the society is to promoting the next generation of scientists. Prior to attending the 2018 Annual Meeting for the Society [For] Biomaterials, I had never attended a professional conference. By being there, I was exposed to areas of research that I did not know about and was able to see firsthand just how broad the field of biomaterials is. Within the field, there are so many applications. This was particularly inspiring for me, especially as I continue to plan my next steps for my research career.

For more information about the Cato T. Laurencin Travel Fellowship or an application, please visit biomaterials.org/awards/cato-t-laurencin-travel-fellowship.

To make a donation to the fellowship in honor of Dr. Laurencin, please contact the Society For Biomaterials headquarters directly at 856-439-0826 or info@biomaterials.org, or visit our website at biomaterials.org/donate. SFB is a 501(c)(3) organization, and all donations are tax deductible.

MARY OMOTOSO

TIMOTHY MASON

The SFB as a Sounding Board for New Ideas

By John (Jack) Ricci, Associate Professor Program, Director, Masters Program in Biomaterials Science, New York University College of Dentistry

One of the things I have always enjoyed about going to the Society For Biomaterials Annual Meetings is the tremendous variety of interests and expertise of the members and attendees at the meeting. Since the early 80s, during my dissertation work, I have been using the SFB meetings as a sounding board to get new ideas and viewpoints. Looking back on this time, there were many interactions that profoundly influenced my research, even if I didn't realize this until much later.

This year, when Harold Alexander and I were awarded the Technology Innovation and Development Award by the Society, I dug back through my old abstract books to see just how much of the work that went into that particular project was presented at SFB.

What I found was a set of 15 abstracts presented between 1991 and 2006 that were all directly relevant to the project. The list of abstracts reads as a direct chronology of the project, starting with in vitro studies of cell interaction with surfaces, progressing to surface prototype development and animal screening studies, progressing through animal application studies, and culminating with the first human data related to the implant surface that was developed during this project, which is now known as the Laser-Lok® surface used on BioHorizons dental implants.

The benefits of presenting every aspect of this project at the SFB meetings were expressed in many ways, and not always in the ways one would expect. There was always the extremely valuable advice by experts in the field, and the kinds of observations that are always enlightening and made by someone with a different scientific background and thus a different way of looking at the same results. But there were also the discussions about the validity of different types of in vitro and in vivo models, and a great many questions from colleagues and students that force one to look a little differently at one's own work. Sometimes these inputs are subtle, and sometimes they are not, but they all have impact and thus value.

In looking back at the history of this project, it is certain that the project would not have worked out the way it did without the Society for Biomaterials. In fact, it may not have worked out at all.

It became a habit for us to always prepare our newest material for the SFB Annual Meeting, and it served us extremely well. The lesson we learned was that we could always count on the SFB meeting for valuable feedback. There was always something new to learn.

IN LOOKING BACK AT THE HISTORY OF THIS PROJECT, IT IS CERTAIN THAT THE PROJECT WOULD NOT HAVE WORKED OUT THE WAY IT DID WITHOUT THE SOCIETY FOR BIOMATERIALS. IN FACT, IT MAY NOT HAVE WORKED OUT AT ALL.

HAVE A LETTER TO THE EDITOR TO SHARE WITH FORUM READERS?

IF YOU WOULD LIKE TO WRITE A LETTER TO THE EDITOR, PLEASE CONTACT GUIGEN ZHANG AT GUIGEN.BME@UKY.EDU. YOUR LETTER COULD BE FEATURED IN THE NEXT ISSUE.

SFB Survey Results on Public Issues

By Joel D. Bumgardner and Martine LaBerge, SFB Representatives to AIMBE Council of Socieities

SFB is a member of the Council of Societies that is part of the American Institute for Medical and Biological Engineering (AIMBE). AIMBE is a nonprofit and honorary organization that provides leadership and advocacy to governmental lawmakers and agencies on policies and issues important to professional medical and bio-based engineering and science societies, academic institutions and industry. The AIMBE Council of Societies was formed 27 years ago in order to share and communicate ideas and strategies for advocating for public policy issues important to constituent societies. The council consists of representatives from 16 professional organizations, including SFB. With increasing budget and political pressures on governmental agencies, there is an urgent need for advocating for the value and importance of medical and bioengineering and science disciplines for improving lives and economy to governmental lawmakers and policy stakeholders.

To help highlight and better inform AIMBE leadership on issues and policy concerns that are important to SFB members, an electronic survey was sent out in March 2018 to current SFB members by its Committee representatives to AIMBE Council of Societies. The survey asked members to rank the following legislative policy issues in order of priority and provided an opportunity to identify other policy issues that are important and should be addressed. (Note: Numbers in parentheses were not included in the original survey but were added after the fact only for discussion purposes.)

- (1) Reduce barriers to innovation imposed by tightening immigration policies.
- (2) Increase federal funding for research (e.g., NASA, National Institutes of Health [NIH], National Science Foundation [NSF], and U.S. Department of Defense/ Congressionally Directed Medical Research Programs research grant programs).
- (3) Increase federal funding to aid in the translation of research funding and development of new technologies (NIH and NSF Small Business Innovation Research and Small Business Technology Transfer grant programs).
- (4) Increase funding for graduate student and postdoctoral training programs (e.g., NIH Fellowship and Career awards, NSF Graduate Research Fellowship Program).
- (5) Increase funding for programs promoting women and under-represented minorities in science and engineering (e.g., NIH URM supplements, predoctoral, graduate and postdoctoral fellowships).
- (6) Smart regulatory reform — Not intended to just slash regulations to make business easier and more profitable, but to streamline processes in a manner that continues to protect patient outcomes.
- (7) Tort reform — It is posited that healthcare providers' sensitivity to liability may lead them to provide excessive care, and that decreasing the liability of pharmaceutical and medical device companies might allow them to reduce the prices of their products and reduce healthcare cost overall.
- (8) Standards for biomaterial fabrication, characterization and functional evaluation: community consensus in biomaterials-related standards and organized effort for standard writing and implementation. National Institute of Standards and Technology, NSF and NIH funding will be needed. This will also boost the smart regulatory reform effort.
- (9) Funding for establishing a national biomaterials foundry in order to promote community biomaterials standardization, serving as a hub for both deposition of biomaterials and fabrication/characterization protocols as well as their distribution to the general biomaterials/ regenerative medicine community.

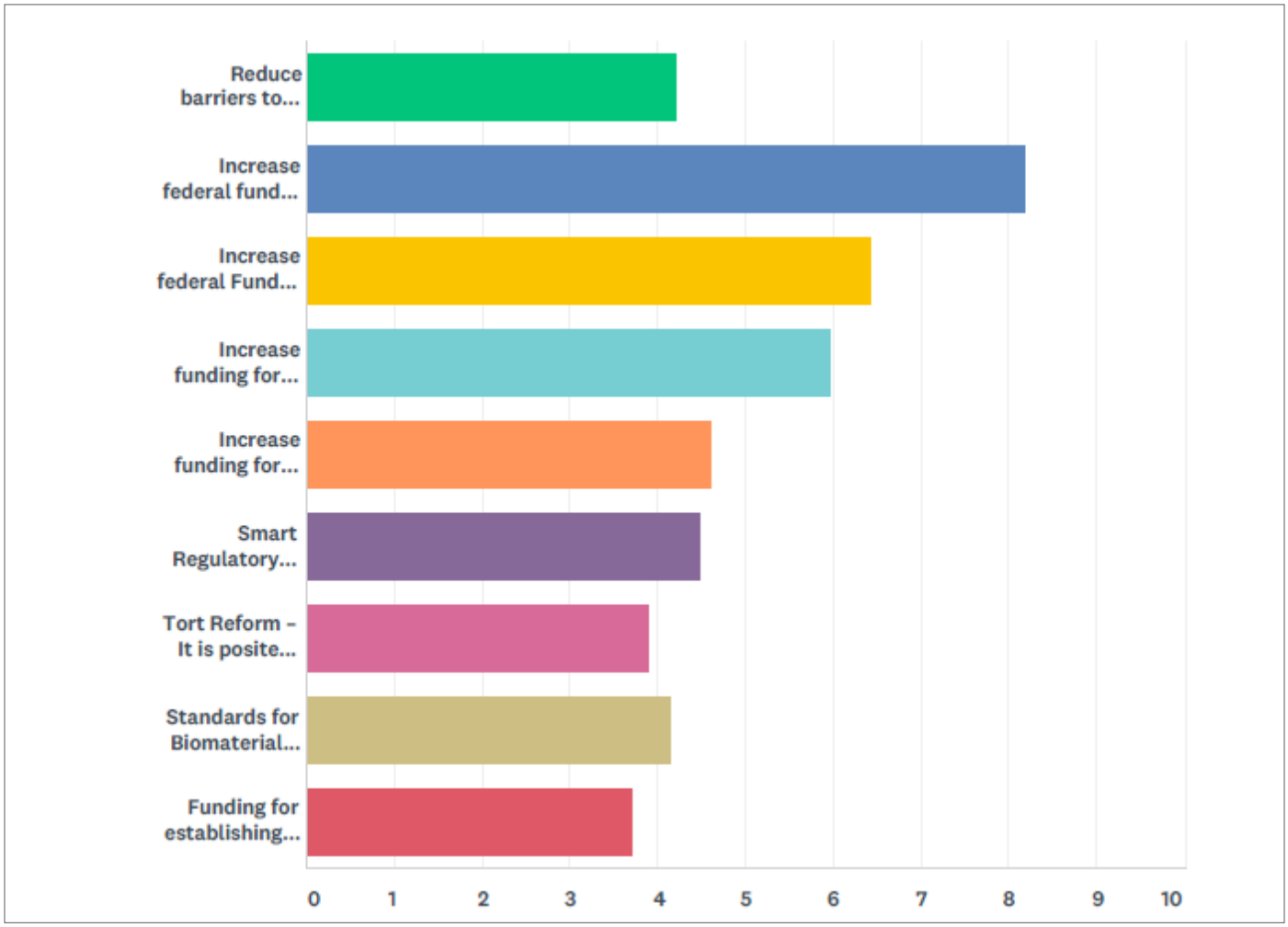
The results of the survey (Figure 1) indicated that the major legislative issues important to SFB members are related to increasing funding for research (basic [#2] and translational [#3]) and for support of graduate student and postdoctoral training programs (#4).

The second group of issues important to SFB members are related to reducing barriers to immigration (#1), increased funding for under-represented groups (#5) and regulatory reform (#6). The third group of issues were related to tort reform (#7), standards for fabrication characterization and functional evaluation (#8), and establishing a national biomaterials foundry(#9).

Other topics of policy interest that members suggested included support of science education TV programs and channels; use of facts to support/direct policy versus the reverse; making college affordable; realistic surrogate clinical trial endpoints by FDA for preliminary device clearance; and allowing NIH contract funding by nonacademic organizations.

These results were presented at the Council of Societies held during the 2018 Annual AIMBE meeting in Washington, DC in

Figure 1



Results of survey for prioritizing policy issues of importance to SFB members for AIMBE policy advocacy development planning. Items are listed in order in which they were listed in the survey.

April 2018. Many of the other societies expressed much support and interest in conducting similar surveys for their membership. Discussions supported the need to increase research funding, but immigration issues related to student, postdoc and young faculty visas were also discussed at length. Because of this information and discussion at the Council meeting, AIMBE leadership will begin obtaining information and providing leadership and guidance on immigration policies that affect medical and bioengineering and science disciplines in addition to continuing efforts to support research and development. This information will be shared with the SFB members on the SFB Advocacy website or via email. Additional information and data related to other policy priorities will be developed by AIMBE as additional information from other Council society members is obtained.

As your SFB representatives to the AIMBE Council of Societies, we strongly encourage you to visit the advocacy pages on the SFB website (biomaterials.org/aimbe-advocacy) to learn more about policies that affect research funding, students, regulatory guidelines, and other topics and how you can become an effective advocate on these issues.

Meet the Rising Stars

Notes from the Editor: *Here is an interview with SFB's 2018 Young Investigator Award winner, Susan Thomas, assistant professor in the School of Mechanical Engineering at the Georgia Institute of Technology. Dr. Thomas' research seeks to develop better ways to treat disease with immunotherapy using biomaterials. Prior to joining Georgia Tech, Dr. Thomas received her PhD in chemical and biomolecular engineering from Prof. Konstantinos Konstantopoulos' lab at Johns Hopkins University and then completed a postdoctoral fellowship in the laboratories of Profs. Melody Swartz and Jeffrey Hubbell at* École *Polytechnique Fédérale de Lausanne.*

Among the most recent awards that Dr. Thomas received in recognition of her innovation are a Komen Foundation Career Catalyst Grant, Department of Defense Career Development Award, National Science Foundation Broadening Participation Research Initiation Grant in Engineering Award, a National Institutes of Health (NIH) National Cancer Institute (NCI) R01 award, an NIH R21 Award from the Innovative Molecular Analysis Technology Program of the NCI, a U01 award from the Physical Science in Oncology program from the NCI, Georgia Tech Professor of Excellence Award, CTL/BP Junior Faculty Teaching Excellence Award, the 2013 Biomedical Engineering Society Rita Schaffer Young Investigator Award, and the 2018 SFB Young Investigator Award. In 2018, she was nominated and selected to attend the National Academy of Engineering US Frontiers of Engineering Symposium.

GZ: First of all, I want to congratulate you again for receiving the SFB Young Investigator Award in April 2018, as well as many other awards. I would like to start by asking: When did you become interested in biomaterials research?

ST: Thank you. It's an honor to be the recipient of such a prestigious award. I am going to nerd out a little bit in my response. I went to graduate school to get advanced research training and was interested in studying how physical forces turn into biological phenomena. That is why I was naturally drawn to the work in Prof. Konstantopoulos' lab. During my training, that interest evolved to include how materials can be used to direct biological processes. I was also fascinated by the immune system and knew that not enough engineers were working on the very good problems in immunology that existed in medicine. But my research to date had focused on mechanical regulators of biology. I was very fortunate to find a postdoctoral position that was the perfect intellectual fit for me — one centered around the intersection with materials science applied to immunomodulation but studied in the context of physiological flows in the body and how they can be exploited for therapeutic delivery. I know this sounds very academic. So what it boils down to in a practical sense is — I wanted to 1) figure out how to build materials to train the immune system for good (to heal; to kill the bad guy cancer cells, infected cells, etc.) and not for evil (cause inflammation, side effects, etc.); 2) figure out how to get those materials and drugs to the tissues and cells in order to do this good and cause no evil.

GZ: Would you give some brief highlights of your research work? What impact you would like to make in terms of helping people and improving quality of life?

ST: I want to develop better ways to get drugs to immune cells in order to train them to fight disease more effectively with fewer side effects. Such knowledge can improve patient quality of life by enabling the development of new biomaterials that can improve immunotherapies that we use for a variety of diseases. One of the particularly innovative ways we are doing this is focusing on delivering drugs to the lymphatic system and lymph nodes, two tissues that are woefully understudied in the biomaterials community but very important in our body's response to any therapy. And it turns out a variety of biomaterials have very unique properties that make them [particularly] good or amenable to interfacing with these tissues — we just need to learn more about how to control these properties in order to leverage them.

GZ: How big is your research group? What can you share with our readers about the ways you run your group and motivate the students and/or postdocs — the challenges and the rewards?

ST: My research group is composed of ~12 members (Figure 1) with postdoctoral fellows and PhD students from diverse backgrounds including bioengineering, materials science and engineering, chemical engineering, mechanical engineering, and chemistry. Our research is uniquely interdisciplinary, so working with colleagues from diverse backgrounds really is an asset. We have a highly interactive group meeting format that encourages question asking and constructive feedback. We also work on communication skills and brainstorming to grow and learn how to ask questions and articulate our work to broad audiences. I have been extremely lucky to work with an extraordinarily talented group of people. Seeing them grow in their scientific careers is extremely rewarding.

GZ: You are very successful in securing research funding from highly competitive sources such as the NIH, the U.S. Department of Defense and the National Science Foundation. In your opinion, what are the keys to such successes?

ST: Hard work, perseverance and working on the right problems for the right reasons. Not everything is en vogue at every moment, but that doesn't make it unimportant. On the other hand, working on problems that people other than you think are important is crucial. So being able to understand your field, develop your unique perspective on that field, as well as articulate why your perspective is important/game changing/will make an impact is the name of the grant-writing game. But it all relies on doing great science and

engineering. As you go through your training, you think the science is hard, then you think the paper writing is hard, then developing the presentations skills, then the personnel/lab management. Then you realize that the real craft is mastering all those other skills in order to be able to effectively find funding streams to explore your ideas, develop your technologies, and be able to make an impact by disseminating your work in journals and delivering new technologies. Balancing all of these aspects of running a lab is challenging, but they also help focus your energies on the right balance of delivering on potential versus developing new ideas. Another important thing: always listen to what reviewers say! There is probably a reason they are making their point.

GZ: What can you share with our readers in terms of the DO and DON'T in research program development, proposal writing, etc.?

ST: Your integrity is the most important thing you have in this business. Be a good collaborator, kind to people in training that are junior to you; listen to everyone but know how to synthesize that advice or information into something you can use positively; contribute to your professional societies; and be a good member of our scientific community. Also, do what you are passionate about, but make sure that passion is grounded in something that will really make a difference in people's lives or in your field. And don't let people discourage your vision. Just learn to keep trying about how to pitch your ideas, and your voice will emerge.

GZ: To date, you have published about 40 papers and received some 20 grants as PI or co-I. What percentage of your time is spent on writing papers and/or proposals?

ST: I don't keep track of time on that, but a lot. And it ebbs and flows how I distribute my time. But turning up your sleeves and getting down to the hard work is what our job is (in addition to the teaching, mentoring, service, of course!).

GZ: A successful young researcher often gives people the impression that work is all of your life. You seem to be doing extremely well balancing work and life by being also a mother of two young girls. How do you do it? Can you share with our readers something about your daughters and your family life?

ST: I am lucky to have an amazing support structure from my husband, who is tirelessly supportive of my career and my teammate in all things in our family life. Despite being a very successful data scientist for a major internet company, he works with me in all ways to raise our family. It is a partnership that I am incredibly lucky but incredibly thankful to have. Our children are still very young (both girls are under three), so we haven't navigated the afterschool activities bonanza of parenting yet, but they require a lot of hands-on care at this early stage in their life. But as I have heard from many parents over the years, children really teach you how to be effective with your time. Georgia Tech is also bustling with many successful faculty that juggle the demands of family life, and it is great to have examples around me and a culture of being invested in you as the whole person — science, family and all — that helps me feel grounded and as though I work in a community that values home life as well.

GZ: Looking ahead, what challenges do you see in realizing the impact you would like to make through your innovative research work?

ST: We are excited to move some concepts and technologies from bench to bedside in the coming years. Luckily, it is a time of explosive growth for the immunoengineering area.

GZ: You mentioned several times about the needs to collaborate and work with the right partners and clinician scientists. How do you identify the right ones?

ST: I took a route less traveled when starting my lab and didn't start collaborations right away, instead focusing on developing our voice, technologies and areas of expertise. Once I had established these things (to some extent at least, you are always growing!), I began what I refer to with my students as "pounding the pavement" — reaching out to clinicians, giving talks in basic science departments, taking meetings all over town and via phone/video conferencing. You then start to figure out who is thinking about problems or has technologies that may synergize with your point of view or technology, etc. You also start to figure out who you jell with since collaborations — good ones at least — really are partnerships. Not every interaction is going to work out, but you have to spread some seeds to see what will grow. Finding people that are passionate, who share ideas that resonate and share your vision is key.

Figure 1

Susan Thomas with her students and postdocs

Figure 2

Thomas and her family while at the 2018 Regenerative Medicine Workshop in Charleston

Conference on Definitions in Biomaterials 2018

By Wanlu Zhao, Sichuan University

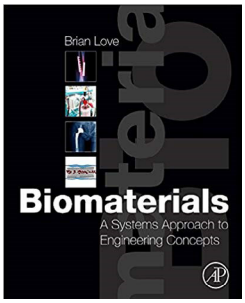
The Conference on Definitions in Biomaterials 2018, hosted by Sichuan University and the Chinese Society for Biomaterials, was held June 11-12 in Chengdu, China, under the auspices of the International Union of Societies for Biomaterials Science and Engineering (IUSBSE), the largest and most authoritative nonpolitical and nonprofit academic organization in the field of biomaterials. More than 50 biomaterials scientists from 17 countries and regions attended the conference. This was the second consensus conference on biomaterials definitions. The first one was held 32 years ago in Chester, UK. The conference was chaired by Prof. Xingdong Zhang (CAE, NAE, FBSE, FAIMBE) of Sichuan University, president of the IUSBSE.

Biomaterials science has evolved as an important discipline since the 1960s, and it has made significant contributions to the development of medical devices and technologies. As in any other emerging field, a large number of new terms and phrases have been developed and used to describe new phenomena and concepts in the field of biomaterials, often with some confusion over their meaning. The European Society for Biomaterials held the first consensus conference on biomaterials definitions in 1986 in Chester, UK, to discuss and standardize biomaterials terms and definitions of the discipline connotation with the outcomes published in the conference proceedings. It was a milestone for the development of biomaterials. Some of the terms discussed and approved at the first conference are still widely used today. With the deepening scientific understanding, new biomaterials and related technologies have been developed and applied in clinical practice since the first conference. The previous definitions need to be re-examined and new definitions created. To meet the needs, Prof. Zhang proposed a consensus conference on biomaterials definitions at the 2017 Annual Meeting of IUSBSE in Athens, Greece. The proposal was approved by the IUSBSE delegates at the meeting.

The executive committee of this conference consisted of Profs. James Anderson (NAE, NAM, FBSE, FAIMBE), Kristi Anseth (NAE, NAM, NAS, FBSE, FAIMBE), Xiaobing Fu (CAE), Kazunori Kataoka (NAE, FBSE, FAIMBE), Cato Laurencin (NAE, CAE, NAM, FBSE, FAIMBE), Keith McLean (FBSE), Nicholas Peppas (NAE, CAE, NAM, FBSE, FAIMBE), Buddy Ratner (NAE, FBSE, FAIMBE), David Williams (FREng, FBSE, FAIMBE) and Xingdong Zhang. The conference was divided into six subject-specific sessions: 1) General Biomaterials, 2) Biocompatibility, 3) Regenerative Medicine, 4) Implantable and Interventional Devices, 5) Drug/Gene/Contrast Agent Delivery, and 6) Emerging Biomaterials and Technologies. Each session featured a plenary speaker, a moderator and a reporter. The approved definitions in each session were summarized and assembled into a list, which was discussed and confirmed at the closing plenary session. The terms introduced in each session were extensively discussed by all attendees. Consensus was achieved for the definitions with at least 75 percent of the votes from all representatives. The output of this conference will be coedited by Profs. Xingdong Zhang and David Williams and published by Elsevier in a book tentatively titled Biomaterials Definitions for the 21th Century. The introduction and summary chapters of the book will be published on the IUSBSE website for open access.

Book Review

By Lynne Jones, Book Review Editor



Biomaterials: A Systems Approach to Engineering Concepts. By Brian Love. Elsevier Academic Press, Cambridge, MA 2017. 387 pp.
ISBN: 978-0-12-809478-5

There are very few textbooks that I start reading and don't want to put down until I am finished. This is one of them. The appeal of this book to me is that it provides the details that are necessary for an appropriate foundation in biomaterials while seeming like a conversation between the author and the reader or, better yet, teacher and pupil. As such, I believe that the conversational style makes the content more accessible to both upper-level undergraduates and graduate students and will also be of interest to biologists, materials scientists, and clinicians.

I must confess my bias. As a biologist, I was pleasantly surprised by the introductory chapters that focus on cell biology (Chapter 1), cell expression (Chapter 2), bones and mineralized tissues (Chapter 3) and connective and soft tissues (Chapter 4). Chapter 1 (cells) and Chapter 2 (cell function: proteins) establish the background necessary to understand the subsequent chapters on specific tissues (Chapters 3-6).

Chapters 7 through 14 review the more traditional topics associated with biomaterials — the materials themselves (Chapters 7, 8 and 9) and medical applications (Chapters 11, 12, 13 and 14). As such, the topics covered within these chapters are similar to those covered in other textbooks, including textbooks that I have reviewed in the past. The information provided is current, and the figures and tables are of value, highlighting the material that is presented. Processing methodology is discussed and is important to our understanding of the *in situ* behavior of biomaterials. While the chapter on orthopedic applications (Chapter 11) provides a good overview of applications of biomaterials in this discipline I'm very familiar with, I especially liked the chapters about use of biomaterials in neural and cardiovascular applications that I know less about. Chapter 12 (Neural Interventions) and Chapter 13 (Cardiovascular Interventions) were interesting and educational; I could easily follow the text regarding the principles upon which the illustrative examples of different applications were based.

There are four chapters that I would like to point out. Chapter 10, Nanomaterials and Phase Contrast Imaging Agents, is included to illustrate that there is "a larger view of ensembles of nanomaterials that, while not consolidated structures, have functional attributes that aid in resolving enhanced phase contrast." The chapter describes the use of nanomaterials to assess gastrointestinal blockage, cardiovascular phase contrast angiography, magnetic resonance imaging phase contrast agents and positron-emission tomography imaging. Chapter 6 is entitled Environmental Effects on Natural Tissues and primarily focuses on diseases associated with aging discussing arteriosclerosis, kidney disease, obesity, osteoporosis, valvular diseases, cancer, amyloid diseases, as well as aging of skin and responses to burns and prior connective tissue trauma. I have always maintained that this is important. Preclinical testing is routinely conducted with normal cells and healthy animal models. Would the responses be different if we looked at these through the lens of disease associated with the tissues that we are reconstructing? I think so.

Chapter 14, Artificial Organs, includes the strategic approaches to kidney dialysis, artificial pancreases and artificial bladders. The chapter ends with a discussion of the experience with artificial hearts and challenges us to continue to improve upon what has been developed so far. Chapter 15, Special Topics: Assays Applied to Both Health and Sports, while only tangentially related to biomaterials, provides a unique perspective to blood doping in athletes. The author indicates that the topic may relate to tissue-engineered constructs, chemotherapy and dialysis. However, I would suggest that this chapter could be used as a springboard to discussion of the definition of a biomaterial — must it be synthetic, or could it be tissue based? It could also be used to discuss bionics and competition in sports.

The book contains a preface (already mentioned) and a postface. I recommend reading both, as they provide a glimpse into the author's objectives and personal insights into the field of biomaterials. This is augmented by the inclusions of learning objectives that introduce each chapter. Each chapter concludes with a list of problems for assignment or discussion. A solution set for the problems is available online.

Getting back to my viewpoint that this textbook is an extended conversation on biomaterials, there are some comments that I would like to offer in response to those of the author. As with many textbooks used to introduce biomaterials to undergraduate and graduate students, ancillary materials are recommended to delve deeper into the fundamental concepts — for example, why specific biomaterials are selected for reconstruction of different tissues. Additionally, topics related to tissue engineering such as scaffolds and cell seeding receive only a cursory discussion. While traditional biomaterials are currently used to reconstruct most tissues today, cell-based constructs are being developed and used to re-engineer the biology associated with these tissues and are likely to play a significant role in the future.

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