NIBIB Strategic Plan Draft 2011

(This document will be followed by an implementation plan detailing the tactics necessary to achieve specific goals and the metrics to measure specific outcomes.)

NIBIB Mission

The mission of the National Institute of Biomedical Imaging and Bioengineering (NIBIB) is to improve human health by leading the development and accelerating the application of biomedical imaging and bioengineering technologies. The Institute is committed to integrating the engineering and physical sciences with the life sciences to advance basic research and medical care.

NIBIB Vision

To bring profound innovation to health care and wellness by pushing the frontiers of technology

Technology development and the discovery of knowledge are vitally interdependent. Advances in technology drive discoveries that create knowledge and further advance enabling technologies. These collective advances in technology and knowledge are the foundation for new diagnostics and treatments and improved health and wellness.

NIBIB Goals

1. ***Improve human health through the development of emerging biomedical technologies at the interface of engineering and the physical and life sciences***

Key Point:

- This goal encompasses the core research we support and provides a cornerstone for our research agenda.

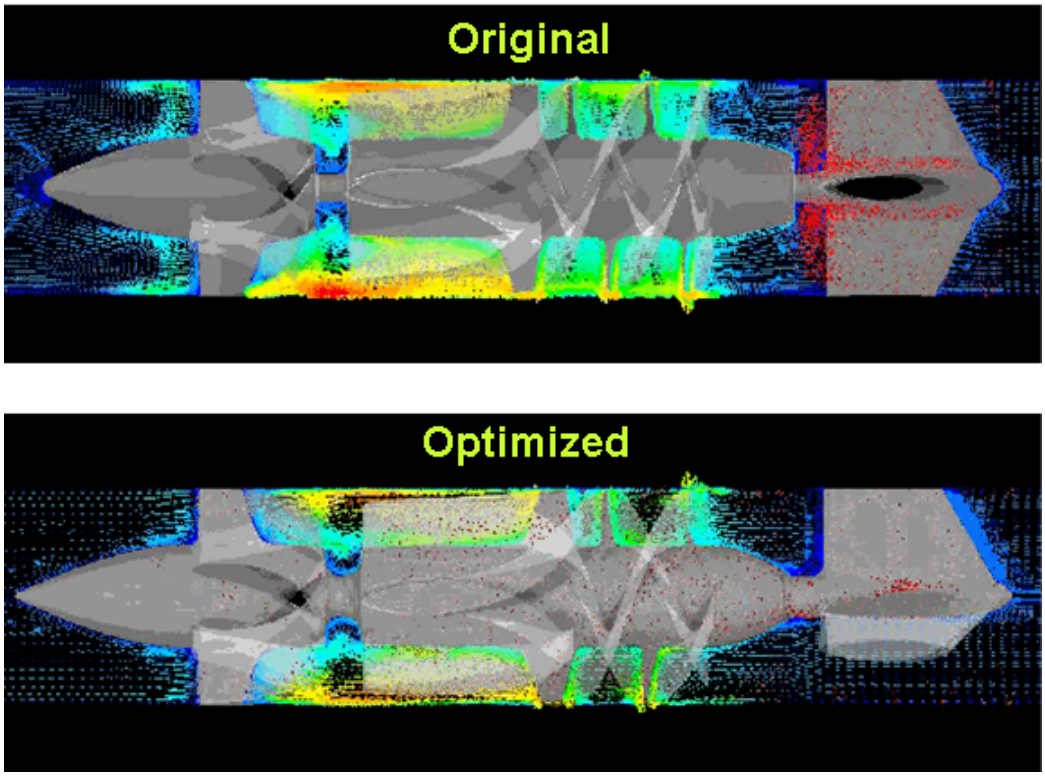
Strategies:

- Serve as the focal point for investigator-initiated grants in imaging, engineering, health informatics, and interdisciplinary science
- Foster and accelerate the translation of new technologies
- Promote the convergence of engineering, mathematics, and the physical and life sciences to advance knowledge in basic biomedical research and medicine
- Nurture a robust, cutting-edge intramural research program with emphasis on biomedical imaging and biomedical engineering research
- Identify and invest in high-impact research with a philosophy that is accepting of high risk and recognizes the possibility of failure
- Foster the application of NIBIB-developed technologies to the diagnosis and treatment of specific diseases through collaboration with other NIH Institutes and Centers

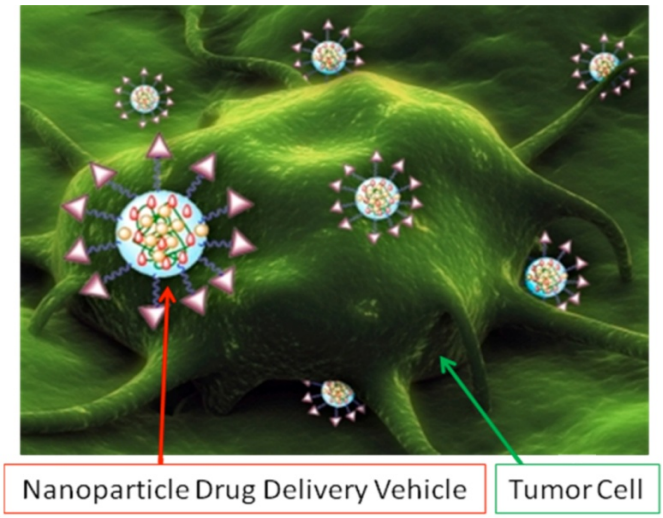
Reducing Thrombogenicity of Cardiovascular Implants

Over 5 million Americans each year suffer from heart failure, but now many lives are saved through the use of ventricular assist devices that reduce the stress on a heart following a heart attack or replace the functions of a failing heart. Although these devices can extend life by more than a year, patients must follow a difficult regimen of anticoagulant therapy because blood flowing inefficiently through these mechanical devices can trigger the formation of life-threatening blood clots.

Dr. Danny Bluestein, a biomedical engineer with a background in aerospace engineering, is paving the way toward eliminating the need for these anticoagulants. With his colleagues at the Stony Brook University, he is conducting something akin to virtual wind tunnel testing of these ventricular assist devices, simulating blood flow through these devices to understand what causes blood clots to form and using this information to optimize the design of the implanted device. Then, in collaboration with Dr. Marvin Slepian, a cardiologist at the University of Arizona and several industrial partners, these optimized devices are tested in animal models to verify if they have reduced clotting properties. Recently, a device optimized in this way was found not to require the mandatory use of anticoagulants, and the long-term goal is to translate this result to human patients, improving the life of patients with these life-saving devices.



Impeller blades propel blood through an implanted ventricular assist device (VAD) to support a failing heart. Dr. Bluestein and colleagues model the passage of platelets (red particles) and the velocity vector flow fields (color map) to redesign the blades, minimizing the stress (red and orange regions) on the platelets. *(Image used with the permission of Danny Bluestein, Stony Brook.)*



Drug-carrying nanoparticles designed by researchers at MIT and Brigham and Women's Hospital bear tags that bind to molecules found on the surface of tumor cells. *(Image used by permission of Patrick Gillooly, MIT.)*

New Nanoparticles for Targeted Cancer Treatment

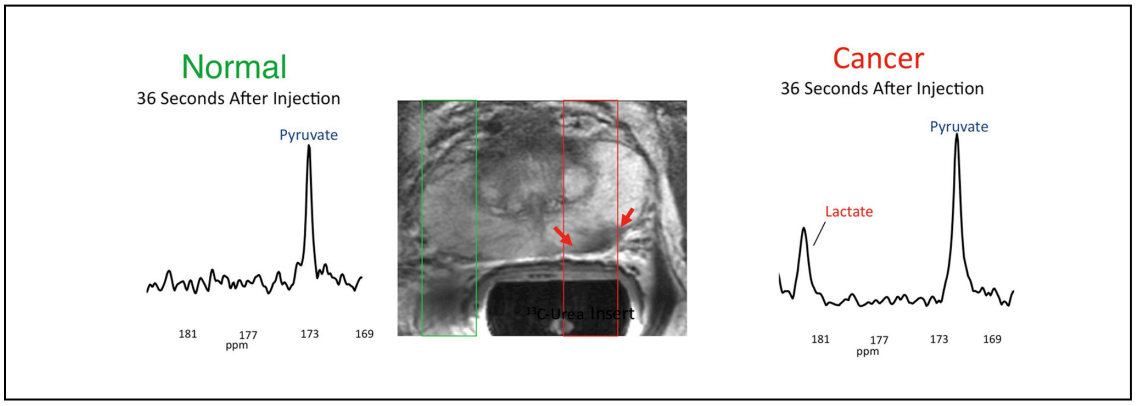
A drug cocktail that is capable of destroying cancer may involve the right drugs delivered to the right location in the right amounts at the right times. The delivery system can be as important as the delivered agents in achieving a successful outcome.

Nanoparticles are being synthesized that are custom-designed to home to cancer cells and deliver chemotherapies that kill the cancer. The outside of the nanoparticles are covered with molecules that recognize surface molecules found on cancer cells but not on normal, healthy cells. After the particles contact a cancer cell, they enter the cell and are specially engineered to release multiple drugs either slowly or quickly, depending on what is most effective for killing a particular cancer. Recently, at the Massachusetts Institute of Technology, advanced nanoparticles have been engineered that are capable of successfully carrying multiple cancer drugs with very different physical properties. The new technique is called drug-polymer blending, and it allows control over drug ratios and release times, offering the opportunity to fine-tune drug combinations and personalize treatment for individual patients.

Metabolic Biomarkers for Improved Monitoring of Prostate Cancer

Each year there are more than 200,000 new cases of prostate cancer in the United States; however, the decision of how to manage the disease is a great dilemma. There is a tremendous range in the aggressiveness of prostate cancer, and options for treatment vary from active surveillance to radiation therapy or surgery. Understanding the metabolic rate of a tumor may provide a faster and better understanding of how aggressive it is, and therefore which treatment may be most appropriate.

Magnetic resonance imaging (MRI) is a very powerful non-invasive method for imaging the human body and detecting abnormal structures like tumors. Dr. John Kurhanewicz and an interdisciplinary team at the University of California, San Francisco, have extended this technique using hyperpolarized carbon-13 magnetic resonance imaging to overlay metabolic information for detected tumors. The team has developed a system for synthesizing, hyperpolarizing, and rapidly delivering carbon-13 labeled pyruvate, a natural human metabolite, to a patient which can be readily detected using a standard MRI scanner. The metabolic rate of the tumor can be assessed by monitoring how quickly the pyruvate is converted to lactate, another metabolite which can also be easily detected (shown below). The long-term goal is to improve risk prediction compared to invasive biopsy and tailor treatment accordingly.



Center: A two-dimensional standard MRI of a human prostate cancer patient showing a "dark" area (red arrows) indicative of prostate cancer tissue. ^{13}C MR spectra from tumor and non-tumor areas of the prostate demonstrate high conversion of injected hyperpolarized pyruvate to lactate in the tumor (*right*) compared to normal prostate tissue (*left*). (*Image courtesy of D. Vigneron, J. Kurhanewicz, S. Nelson, University of California, San Francisco.)*

2. *Enable patient-centered health care through development of health informatics and mobile and point-of-care technologies*

Key Points:

- Patient-centered health care requires the integration of patient-related medical information from all sources, including medical centers, walk-in clinics, and home devices. This comprehensive information must be accessible to both patient and provider.
- Access to the complete health care record is controlled by the patient.

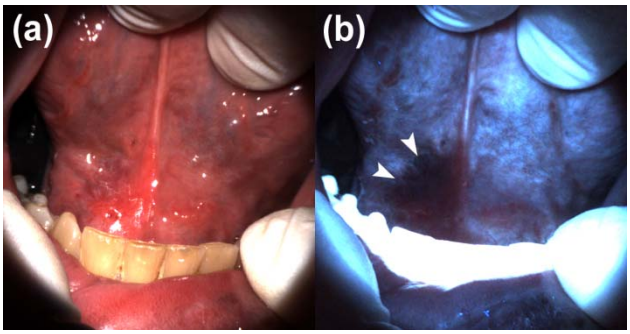
Strategies:

- Develop improved sensor and information technologies for home and mobile use that will sustain wellness and facilitate coordinated management of chronic diseases
- Promote the development of low-cost, efficient, and effective point-of-care technologies
- Advance wireless and mobile health technologies and integrate point-of-care technologies with medical information systems
- Support informed clinical decision making through evidence-based decision research

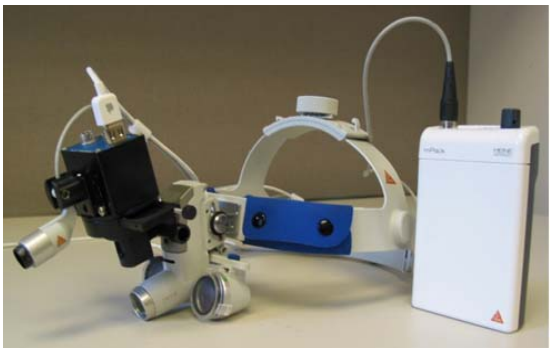
Autofluorescence Imaging for the Early Detection of Oral Cancers

Oral cancer is the sixth most common type of cancer worldwide, with over 400,000 new cases and 127,000 deaths in 2009. Most patients present with advanced tumors for which treatment is less successful and more expensive than early-stage intervention. There is significant interest in detecting and diagnosing pre-cancerous lesions and early-stage cancer during routine dental exams, requiring easy-to-use, reliable, portable technology that is fast and accurate.

To address this need, Dr. Rebecca Richards-Kortum, Dr. Ann Gillenwater, and their collaborators at Rice University have developed a portable head-mounted multi-modal optical imaging system that can detect the presence of abnormal cell structures by a change in the natural autofluorescence of tissue. The team is now comparing this rapid, noninvasive screening technique to the histopathology gold standard and developing software to automate and improve detection.



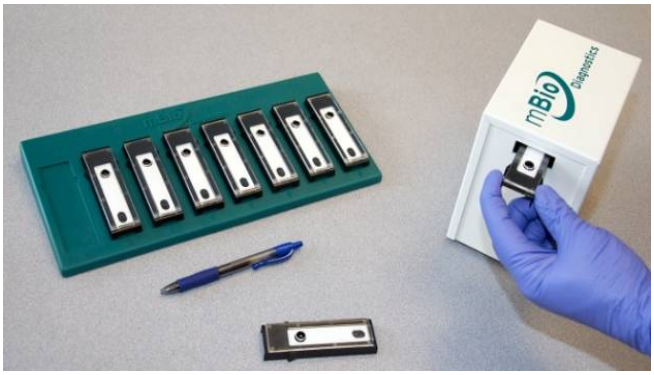
Images of a lesion on the floor of the mouth imaged (a) with white light, and (b) with autofluorescence mode (excited at 405 nm). A region showing loss of autofluoresence intensity can be seen in (b), the border of which is indicated by arrows. Tissue specimens obtained from this region during surgery exhibited mild, moderate, and severe dysplasia on histopathology.



Portable, head-mounted, battery-powered device for autofluorescence and reflectance imaging, built into a commercially available Heine headlamp. (*Images courtesy of Rebecca Richards-Kortum, Rice University.*)

Point-of-Care Testing to Improve Global Health

In many developing countries, diagnostic capabilities are minimal, inadequate, or nonexistent. Innovative and appropriate point-of-care diagnostic technologies can mean the difference between the right treatment or continued sickness or death and can improve public health by providing timely and appropriate treatment guidance as well as early detection of emerging diseases.



This low-cost disposable cartridge system can simultaneously test blood samples for multiple infections, including HIV, syphilis, and Hepatitis B and C. In collaboration with PATH, mBio Diagnostics™, Inc. has begun to field test the device. (*Image provided courtesy of Michael J. Lockhead, Ph.D., mBio Diagnostics™, Inc.)*

Dr. Bernhard Weigl and colleagues at the Program for Appropriate Technology in Health (PATH), in collaboration with the University of Washington, lead a center to advance point-of-care diagnostics for global health. This center works with both academic and private sector partners to fund, evaluate, and if appropriate take into the field for testing a wide range of diagnostic tests, including tests for diarrheal disease, syphilis, Chagas disease, and HIV, as well as technologies for the management of undifferentiated febrile illness in children. The center also trains researchers from around the world in how to assess clinical needs, building a strong global network for advancing point-of-care diagnostics.

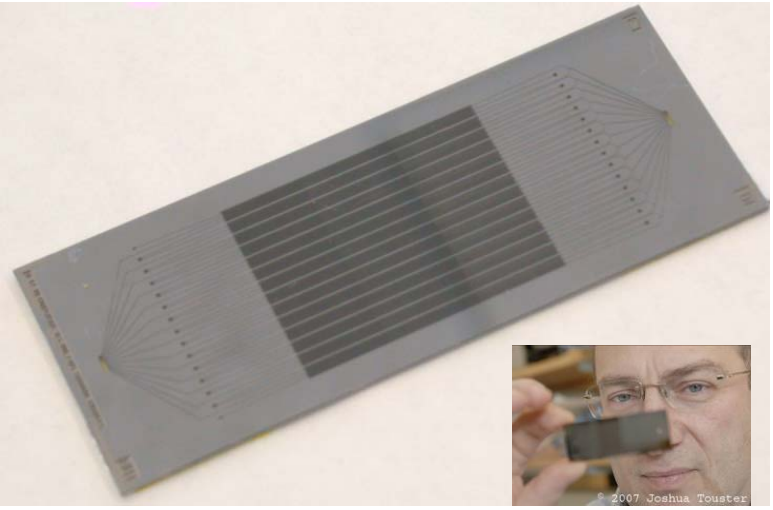
3. Transform advances in medicine at the molecular and cellular level into therapeutic and diagnostic technologies that target an individual's personal state of health

Key Points:

- Take advantage of genomic, proteomic, and metabolomic data to stratify subgroups of patients for personalized, targeted treatments.
- Understanding of disease mechanisms at the molecular and cellular level is required to realize individualized therapies targeted to specific disease cells. Technologies that isolate and identify these cells in an individual patient can translate this knowledge into improved prevention strategies, diagnostics, and therapeutics.

Strategies:

- Develop novel high-throughput methods and technologies to identify or screen cellular and molecular markers that can characterize disease sub-types
- Engineer devices that incorporate cellular or molecular markers for diseased cells with capability for single-cell isolation
- Develop high-throughput imaging and bioengineering technologies to study single-cell biology in individual patients
- Develop state-of-the-art informatics and computational tools to process and analyze high-volume data sets
- Advance the engineering of biologically-inspired synthetic approaches to make breakthrough diagnostic and therapeutic discoveries that will transform medicine



A microfluidic slide containing microposts that detect cancer cells in samples of human blood. *Inset:* Dr. Mehmet Toner. (*Image courtesy of Dr. Mehmet Toner, Massachusetts General Hospital.*)

Point-of-Care Devices for Early Detection of Cancer

The early detection of cancer is critical to improving patient outcomes, but it is like looking for a needle in a haystack. It is believed that tumors can metastasize through cancer cells being shed into the blood system. However, a high-throughput system with very high efficiency for detecting these rare cancer cells is required.

Dr. Mehmet Toner and his team at the Massachusetts General Hospital have developed a disposable microchip capable of detecting and separating rare circulating tumor cells from whole blood samples at concentrations less than one cell in a billion. These microfluidic devices have been successfully used to track the number of circulating tumor cells in cancer patients and correlated to the treatment of their tumors. Individual cells that are captured need to be indentified to understand where they came from in the body for follow-up studies, so the team is currently working to integrate their microfluidic chips with single-cell analysis to provide genetic analysis of the cells that are captured.

4. *Develop medical technologies that are low-cost, effective, and accessible to everyone*

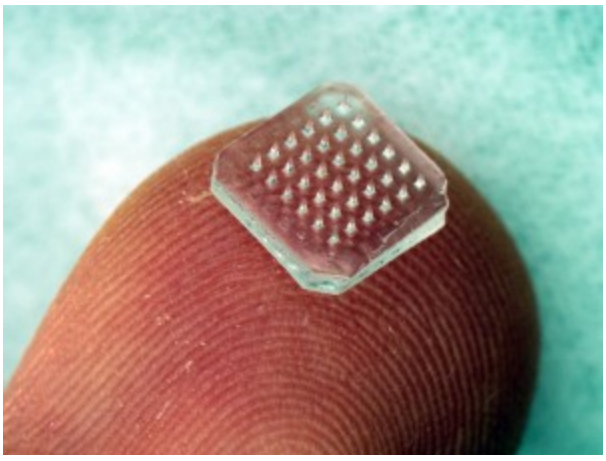
Key Point:

- New technologies are needed that are both effective and low-cost to achieve health care equity within the United States and around the world.

Strategies:

- Develop novel, low-cost medical technologies. Support their translation to routine clinical use by partnering with other NIH institutes and centers, other federal agencies, and the health care industry
- Develop low-cost, state-of-the-art medical technologies that are easily placed, maintained, operated, and culturally accepted in underserved, low-resource communities
- Capitalize on telecommunication and mobile health technologies to broaden the accessibility and affordability of health care in remote environments

Influenza Vaccination Using a Patch



A micro-patch is shown here on a fingertip for size comparison. (*Image courtesy of Jeong-Woo Lee, Georgia Institute of Technology.)*

Influenza is a major cause of morbidity and mortality worldwide, and despite annual vaccination campaigns in the United States there are more than 36,000 deaths and 226,000 hospitalizations each year. Vaccination is an effective strategy to prevent infection, and the number of cases could be greatly reduced if more people were vaccinated and if the vaccination was more effective.

Dr. Mark Prausnitz and his team at the Georgia Institute of Technology are addressing both issues by developing a dissolvable micro-patch that will allow people to vaccinate themselves. Applying the patch is minimally invasive and painless, takes just seconds, and results in an enhanced immune response. Additionally, there is no sharp biohazardous waste, and the patch does not require refrigeration during storage or distribution. These characteristics make it an ideal platform technology for delivering and administering many types of vaccines, including those in response to a pandemic or for global health programs.

Low-Cost, Widely Accessible Ultrasound for Maternal Health

Women and children wait outside a medical clinic in Africa. (*Photo by Wernher Krutein, Photovalet.com.*)

In many rural and underdeveloped areas, childbirth mortality continues to be significant. In the United States, about 500 mothers die every year during childbirth, and in Africa, childbirth-related deaths are nearly 300,000 annually. Many of these deaths could be prevented if these populations had ready access to prenatal exams that identify mothers at high risk for birth complications so that they can be cared for properly in preparation for birth.

NIBIB researchers are developing ways to fabricate the critical components of ultrasound systems more cost effectively. For example, Dr. Scott Smith, a physicist in the Imaging Technologies Lab at GE Global Research, is working with a new technology called Digital Micro Printing, which utilizes a unique ceramic and polymer system. The work aims to develop a new generation of ultrasound probes that could be produced at a fraction of the current cost. The broad goal is to make ultrasound imaging as pervasive as other simple diagnostic equipment like stethoscopes, with the ultimate result being vastly improved health outcomes for expectant mothers around the globe.

5. *Develop training programs to prepare a new generation of interdisciplinary engineers, scientists, and health care providers*

Key Point:

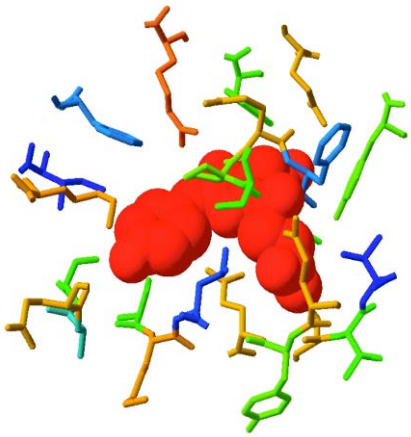
- We will promote interdisciplinary training of investigators at the interface of medicine, engineering, and the physical and life sciences.

Strategies:

- Support team-based engineering design training at multiple career levels, ranging from undergraduate education to post-graduate training
- Develop a cadre of biomedical researchers with training experience in industry, the clinic, product development, and regulatory issues
- Increase diversity in the imaging and biomedical engineering workforce by encouraging the recruitment and retention of underrepresented individuals at multiple career levels
- Support the career development of future research-oriented medical imaging and bioengineering leaders

NIBIB Builds Research Experience of Future Scientists

Donald Johnson, Jr. obtained his B.A. with Distinction and Honors from Occidental College, Los Angeles, CA, in 2008. Don received an NIH Intramural Training Award to perform research in NIBIB's intramural program, under the mentorship of Dr. George Patterson, who heads the Biophotonics Section. Don's research focused on fluorescence imaging experiments that play an important role in helping to understand the basis of human diseases and ultimately to determine targets for drug therapy. He plans to pursue his research interests developed at NIBIB at the University of California, San Diego.



Left: Partial molecular structure of Ds-Red fluorescent protein. Atoms of chromophore are shown as red spheres and surrounding amino acid residues as sticks in alternating colors that correspond to chemical bonds. *(Image courtesy of D.D Johnson, Jr., and G.H. Patterson.) Right:* Donald Johnson, Jr. (P*hoto courtesy of Jude Gustafson.*)

Dr. Ann-Marie Broome

Developing the Interdisciplinary Skills of Mid-Career Scientists

Dr. Ann-Marie Broome was a research assistant professor with a Ph.D. in cell biology and neuroscience in the Department of Biomedical Engineering at Case Western Reserve University when she received a Mentored Research Scientist Development Award (K01) from the NIBIB. Under the supervision of her mentor Dr. James Basilion, a renowned expert in molecular imaging, she has been working on detecting and imaging combinations of biomarkers that uniquely identify cancers from normal tissue and provide information about the biochemical status of cancer cells. These expression patterns or cancer signatures can be indicative of the type, stage, or severity of disease.

6. Expand public knowledge about the medical, social, and economic value of bioengineering, biomedical imaging, and biomedical informatics

Key Points:

- Unlike most Institutes at the NIH, the NIBIB mission is focused on the development of technologies that could impact a wide range of diseases. As such, explaining the importance of our research for improving the health of individuals is a unique challenge.
- NIBIB-supported technologies are extraordinarily valuable for improved prevention, diagnosis, and treatment of numerous diseases due to their cross-cutting nature.

Strategies:

- Promote public understanding of how bridging engineering and the physical and life sciences can improve human health
- Increase and enhance awareness of NIBIB-funded research through multiple avenues including press releases, Director's editorials, the website, and a newsletter
- Expand medical imaging and bioengineering information through social media outlets
- Convene conferences in collaboration with medical societies to promote biomedical imaging, bioengineering, and other biomedical sciences and technologies

Health Care and Patient Advocacy Groups Visit NIBIB

An NIBIB intramural scientist captures the imagination of visitors as she enthusiastically explains her ongoing experiment. (*Image courtesy of Jude Gustafson.*)

NIBIB uses a range of activities to educate the public about the unique contribution of biomedical imaging and bioengineering for improved health care. One of numerous outreach activities features collaboration between NIBIB and the Coalition for Imaging and Bioengineering Research (CIBR), aimed at introducing patient advocates to the NIH and its research programs. These popular tours feature an overview of biomedical imaging and bioengineering technologies presented by NIBIB Director Roderic I. Pettigrew, as well as visits to the NIBIB intramural laboratories where visitors receive hands-on demonstrations of innovative technologies with the potential to vastly improve human health.

NIBIB Participates in the 2010 USA Science and Engineering Expo in Washington, D.C.

As part of its educational outreach activities, NIBIB participated with other NIH Institutes in the 2010 USA Science & Engineering Expo in Washington, D.C. It was standing-room-only for the "Who Wants to be a Bioengineer?" quiz show held on the National Mall. This event provided an opportunity for children to participate in teams to answer questions on topics such as tissue engineering, robotics, and nanotechnology.

Left: Dr. Albert Lee of NIBIB emcees "Who wants to be a Bioengineer?" at the USA Expo. *Right:* Young "Bioengineers in Training" discuss their "final answer." (*Images courtesy of Jude Gustafson.*)