2016 VASEM SUMMIT REPORT

SMART AND CONNECTED HEALTH
PRECISION MEETS POSSIBILITY

VIRGINIA ACADEMY OF SCIENCE, ENGINEERING, AND MEDICINE

VASEM

Contents

WOON-HONG YEO

MESSAGE FROM SENATOR MARK WARNER

Dear Friends,

Healthcare in the United States is undergoing a profound transformation. As our population continues to age and new innovations drive changes in care, we need to bring America's healthcare system into the 21st century, focus on improving quality of care, and enhance the so-called "Triple Aim" of better care, lower costs, and better outcomes for patients.

I was pleased that the Virginia Academy of Science, Engineering, and Medicine (VASEM) chose Smart and Connected Health as the theme of their annual summit. As this collection of summit highlights reveals, the Commonwealth possesses all of the key components necessary to make Virginia a leader in this field—breakthrough research, an abundance of talent, access to capital, and a supportive state government.

We have always been fortunate to have a group of distinguished speakers with a remarkable breadth of expertise. This year was certainly no exception. It is my hope that the events at this year's summit will continue to foster a greater dialogue among Virginia's members of the National Academies, their protégés, and leaders in the public and private sectors who share our commitment to science, engineering, and medicine. Going forward, I hope that VASEM will continue to promote a vibrant intellectual exchange about these disciplines and serve as a resource to the Commonwealth.

Thank you again for joining us and for your involvement with VASEM.

Sincerely,

Mark R. Warner
United States Senator

Above: Wearable skin-like electronics developed by Woon-Hong Yeo can be used for medical sensing.

CYBERSECURITY AND HEALTH: THE WICKED PROBLEM OF KEEPING HEALTH DATA SECURE IN A CONNECTED WORLD

WENDY NILSEN

The vulnerability of healthcare data was underscored in February 2016 when hackers took control of the computer system at a Los Angeles medical center and held it for ransom. The hospital paid $17,000 in bitcoin to regain use of its files.

Wendy Nilsen, program director for the National Science Foundation's (NSF's) Smart and Connected Health Program, cited this incident to highlight the vulnerability of the U.S. healthcare system to cyberattack. She noted that patient records have been a particular target for hackers. In 2015 alone, she said, more than 110 million patient records were breached. No organization is immune. Insurers, hospitals, medical informatics companies, and county medical offices were among the victims. In her view, the healthcare system has a cybersecurity crisis on its hands.

The root of the problem, she pointed out, is cultural as well as technological. Hospitals have gone digital, but their culture remains stubbornly analog. Nilsen noted that before the advent of electronic medical records, patient folders were carried by hand from office to office, and record carts were sometimes left unattended in hallways. This mindset has not changed significantly since records were digitized.

She recalled that when she started to formulate the Smart and Connected Health program, she met with colleagues in the Department of Defense, who talked about how they simply imposed encryption on their employees. "Health is a very different cultural space," she said.

Nilsen cited the experience of David Kotz, the Champion International Professor of Computer Science at Dartmouth University and a principal investigator of the NSF-funded Trustworthy Health and Wellness program. "He was shocked by what he saw in healthcare," she said, which included medical students charged with keeping a secure computer awake so it would not log other medical professionals out.

Given these attitudes, Nilsen said, most data breaches in health have been caused by human fallibility. She cited a 2010 study that listed the top three causes of data breach as employee action, lost or stolen computing devices, and third-party error.

The bottom line: clinicians appreciate the benefits of connected healthcare data in improving outcomes, but they do not understand the need for cybersecurity measures that seem to interfere with their ability to care for their patients.

When health-related tasks flow back and forth between mobile devices and cloud-based services, there are vulnerabilities every step of the way.

Healthcare Cybersecurity at a Crossroads

Concern about this situation is increasing, not just among healthcare professionals but also among members of the general public. Although the baby boomers have not been especially critical of security lapses, digital natives such as the millennials are. "Young people do not feel the same reverence about healthcare institutions that their elders do, and they are very conscious of their privacy," Nilsen said. "They want us to address these issues."

Healthcare certainly offers a rich target for hackers, she said. Electronic medical records include such personal information as medical tests, imaging results, diagnoses, and drug prescriptions. Access to even part of this information—when combined with publicly available personal and financial information—can create a revealing picture of a person's health.

As medicine becomes more reliant on digital systems, the risk of medical devices or medical technology being compromised is also a potential problem. "We have not seen these attacks happen yet," Nilsen noted, "but we know that they are feasible."

The challenges of cybersecurity, however, are complex. For instance, when health-related tasks flow back and forth between mobile devices and cloud-based services, there are vulnerabilities every step of the way. The networks that connect these devices to the cloud may not be secure, and not all cloud-based data repositories adhere to healthcare standards for privacy and security.

In addition, Nilsen noted that data move constantly from platform to platform, from an electronic medical record system, for instance, to a billing system. The points at which these systems connect can be vulnerable to intrusion.

Another issue is secure data entry. Providers are not the only ones inputting patient information. Receptionists in clinics, patients at home, and even wearables on their wrists are beginning to contribute to medical records. Authenticating this wide variety of human and mechanical users is itself a significant challenge.

The need to address these issues is not simply a matter of preserving privacy. It also affects the future of medical research. If researchers are to realize the potential of precision medicine, they must aggregate and analyze untold millions or trillions of data points. The accuracy of their conclusions depends on the security of these data.

A Wicked Problem

These are just some aspects of what Nilsen refers to as a wicked problem, one that cannot be solved by researchers from a single discipline. She believes that we must devise solutions that, from a technical perspective, provide privacy and security while also addressing the way members of the healthcare community use the system.

In Nilsen's view, this is a challenge that requires researchers from different disciplines to work together to integrate theory, methods, and concepts that extend discipline-specific language and models. "There are really huge and exciting issues to confront here," she said, "but they cross boundaries."

This type of transdisciplinary research, she observed, is an NSF priority, and she cited two NSF programs that are addressing the problem of keeping health data secure in a connected world. The first is the Secure and Trustworthy Cyberspace program, the largest unclassified cybersecurity research program in the world. It awarded more than $75 million during the FY16 grant cycle and made approximately 200 new grants during FY15.

The second is the Smart and Connected Health program, for which Nilsen serves as a program director. The idea behind Smart and Connected Health is that breakthroughs in areas such as sensor technology, networking, and machine learning can lead to a fundamental transformation in healthcare, changing it from a reactive and hospital-centered system to one that is proactive, person-centered and focused on well-being rather than disease. For all these aspirations to be realized, Nilsen stressed, cybersecurity is essential.

Wendy Nilsen, PhD, is a program director for the Smart and Connected Health Program in the Directorate for Computer and Information Science and Engineering at the National Science Foundation.

SPACE MEDICINE AND 3D PRINTING: DEVICE DESIGN AND DEVELOPMENT

MELVIN GREER

NASA

"The exploration of health in space began in 1961 when the Soviet cosmonaut, Yuri Gagarin, became the first human to enter Earth orbit, and it continues at NASA to our day," said Melvin Greer, managing director and senior research fellow at the Greer Institute.

The prime concern of the National Aeronautics and Space Administration (NASA) is preserving the health of astronauts in the microgravity of the International Space Station (ISS) and developing systems to respond to emergencies. Finding ways to address the health issues at the ISS has been a constant concern for NASA, but fortunately careful screening and training have meant that there have been no emergencies. Greer cited figures that show that on the Space Shuttle between 1981 and 1998, astronauts and their flight surgeons dealt with over 1,860 medical events. By far, the largest number were related to space adaptation syndrome. Fortunately, even the rare circulatory and endocrine issues were minor and well within the capability of the medical equipment onboard and the skills of the crew medical officers.

NASA has developed a highly sophisticated program to preserve the health of its astronauts. Greer described the ISS Crew Health Care System, which has three major components:

- A countermeasures system that includes exercise and fitness evaluation.
- An environmental system that addresses gas, water, and acoustics quality.
- A health maintenance system that includes health monitoring and care.

This system generates an enormous amount of data on astronaut health, approximately 2.5 terabytes, each day. These data allow NASA to personalize the healthcare it offers each astronaut and to anticipate health issues on ISS.

At the same time, it is nonetheless true that many of the insights gained from observing human beings in space and the techniques developed to care for them also have application to medicine on Earth. These include improved methods to promote cardiovascular recovery and prevent osteoporosis, new biological and immunological tools, and advanced remote health technologies. "No one does telemedicine like NASA," Greer said.

Greer also noted that experiments on ISS with autonomous surgery systems, plasma torches to kill bacteria, and low-power Halbach magnets for diagnosis set the stage for more advanced robotics, better infection control, and more compact mobile MRI on Earth. "These are exactly the kinds of transdisciplinary activities and techniques that we are targeting when we talk about the convergence approach to scientific development," he said.

Moving Medicine into Deep Space

As Greer pointed out, the pace of space-inspired healthcare innovation will, of necessity, increase as human beings move out of Earth orbit into deep space. "If we are to successfully colonize asteroids and establish a base on Mars or the Moon, we are going to need to rethink how we provide medical care," he said

For instance, Greer cited the challenges of performing surgery in deep space. "It raises a number of questions," he said. "Can we perform surgery over a network? And if not, can we apply machine learning and artificial intelligence to enhance autonomous surgery?"

"If we going to start taking advantage of the opportunities of deep-space exploration," he added, "we are going to need to find ways to help people stay healthier, live just as long as they would on Earth, and have a better quality of life than they do now on the ISS."

3D Printing for Extended Spaceflight

One step in this direction, Greer believes, was the permanent installation in 2016 of a 3D printer in space. In 2014, the Center for the Advancement of Science in Space sent up a 3D printer to determine if the technology was feasible in microgravity. The lack of gravity dictated that they use a printer with a unique filament rather than a powder or liquid resin. NASA engineers were also interested in testing the idea of having an in-station space shop, where additive manufacturing could be used to make a variety of parts.

The first 3D printed tool was a wrench. "Having a 3D printer on the spacecraft will increase its range and self-sufficiency and enable it to move into regions of space in which resupply is difficult, if not impossible," Greer said.

Greer noted that in addition to on-demand digital part manufacture, 3D printing could be used for a wide variety of purposes during extended spaceflight. These could include on-demand foods that meet specific nutrition requirements, bioprinting of tissues and biological devices, and direct tissue repair and organ replacement. As have previous advances in space medicine, these innovations will have an analog on Earth. The Virginia Commonwealth University is already conducting pioneering work on 3D printing of prosthetic limbs, patient-specific mandibular constructs to support restoration of dentition, cranial plates, and dental meshes as well as the construction of presurgical models from radiological scans. The need to develop 3D printers capable of meeting the needs of extended space travel will no doubt lead to a surge in development for applications on Earth.

One bottleneck to maximizing the utility of 3D printing in space is the availability of design files. In the past, NASA sent them as needed as an email attachment. In conjunction with Lockheed Martin, Dell, Hampton University, and the Greer Institute, VCU students created a cloud-based additive manufacturing repository, filled it with 3D printer files for parts of the Orion spacecraft, and conducted a 3D printing demonstration from the cloud. An important component of this system was the use of advanced analytics to determine if the 3D part as printed matched the .STL design file. This assures that there are no errors in the printing process, an important consideration in deep space.

Greer concluded by noting that 3D printing will be an enabling technology for deep space exploration, but that there is a great deal to be accomplished before it is equal to the task. He is convinced, however, that the way to make it a reality is through collaboration across multiple disciplines.

Melvin Greer, MS, is director of data science and analytics at Intel Corporation and founder and managing director of the Greer Institute for Leadership and Innovation. He is a member of the American Association for the Advancement of Science.

POINT-OF-CARE TECHNOLOGIES: PHARMACY ON DEMAND

GEOFFREY LING

Geoffrey Ling, the founder and COO of On Demand Pharmaceuticals, began his presentation by describing how essential it is that medications be available at the point of care. As a critical care physician, Ling was deployed in Afghanistan and Iraq, where he treated hundreds of warfighters. Initially, Ling recalled, he assumed that the soldiers were receiving care comparable to that of any major hospital in Washington or Northern Virginia. However, he soon saw a major shortcoming: medications that were commonly available in the United States could not be found in theater.

DEPARTMENT OF DEFENSE

He recalled a time during his first deployment in Afghanistan when he wanted to administer a medication called bromocriptine to a soldier with a head wound only to find that the unit's pharmacy had only a basic set of medications. He prescribed an alternative treatment, which was not nearly as effective. Ling said he felt terrible that he had not met his obligations to this soldier.

Ling, who holds a doctorate in pharmacology, recognized that he could produce bromocriptine at the point of care if he could capitalize on innovative manufacturing techniques. He conceived of the idea of a pharmacy on demand.

For Ling, the impetus to rethink the drug manufacturing paradigm only intensified when he returned to the United States and served as the founding director of the Biological Technologies Office at the Defense Advanced Research Projects Agency (DARPA). In the United States, the issue was not simply availability, but also price, especially for generic drugs. For example, pyrimethamine, approved in 1953 to treat toxoplasmosis, a disease that today affects patients with AIDS or those undergoing chemotherapy, rose from $1 a dose in 2010 to $750 a dose in 2015. Congressional panels determined that this was the result of overseas manufacturing, limited distribution channels, and simple price gouging. "I thought there needed to be a better way," Ling says.

Ling has formed a company—On Demand Pharmaceuticals—to commercialize and expand technology developed for DARPA to produce inexpensive generics. His manufacturing platform uses automated continuous-flow chemistries and microfluidics to inexpensively generate large quantities of different pharmaceutical-grade generics, including diphenhydramine, lidocaine, diazepam, and fluoxetine. Creating this platform required his team to develop new synthesis methods and reaction schemes that were successful under continuous-flow conditions. They are working on processes for manufacturing biologicals as well as small-molecule organic medications.

Ling noted that one of the applications he is particularly excited about is providing anti-retroviral therapies for Africans with HIV, a project he is exploring with colleagues at Virginia Commonwealth University. "The drugs could be delivered by drone to patients," he said. The VCU team, led by Frank Gupton, chair of Chemical and Life Science Engineering, has been funded by the NSF, DARPA and the Bill & Melinda Gates Foundation to develop flow chemistry methods that can reduce the cost of the ingredients for drugs needed to treat critical diseases like HIV, tuberculosis, and cancer.

Ling hopes that On Demand Pharmaceuticals will submit a proposal to the FDA for its manufacturing platform within 18 months and will gradually expand the medications that it can produce. "Our goal is to improve society by making inexpensive generics readily available where they are needed most," he concluded.

Geoffrey Ling, MD, PhD, retired as a colonel in the U.S. Army Medical Corps. He is the founder and COO of On Demand Pharmaceuticals; interim vice chair of research, neuroscience, at Inova Fairfax Hospital; professor of neurosurgery at the Uniformed Services University of the Health Sciences; and professor of neurology at Johns Hopkins.

POINT-OF-CARE TECHNOLOGIES:
PATIENT-OPERATED, SMARTPHONE-BASED DIAGNOSTICS FOR PEDIATRIC DISEASES

WILBUR LAM

As Wilbur Lam recalled in his presentation at the annual VASEM summit, he first saw the potential of basing diagnostic and medical devices on smartphones as a teaching assistant earning his doctorate in bioengineering at the University of California at Berkeley. "Starting in 2008, we challenged successive classes of undergraduate optics students to take off-the-shelf parts and use them to transform a cellphone into a portable microscope," he said. "In a few short semesters, they had a working prototype of a new device, which we dubbed the Cellscope."

Brainstorming with colleagues, Lam came up with several ideas for the Cellscope, but the introduction of the iPhone 3G and its consumer-quality digital camera decided them. They made a simple attachment, wrote a custom app, and created a smartphone-based otoscope that could potentially improve treatment for pediatric ear infections, reduce emergency room visits, improve physician training, and cut healthcare costs.

In California, where Cellscope is based, Lam said that parents can purchase the Cellscope Oto and use it to produce a diagnostic-quality photo or video of their child's eardrum. They can then upload the images, video, and other relevant information to a HIPAA-compliant web-platform, which incorporates the child's data into his or her medical record. Their providers can view a sequence of these images to determine if the child has been improving.

This is just one instance, Lam said of how smartphone-based devices can improve medical care. He cited two more that he has developed, the first of which was inspired by a young girl with sickle cell anemia in his clinic at Emory University, where it is now based. "I had a patient ask why there wasn't a simple device she could use to track her hemoglobin, much as her sister used a glucometer to monitor her blood sugar," he said. "She asked why, as an engineer, I wasn't doing something about it."

As it turns out, there is an existing device that works like a glucometer, but it is expensive. Lam's challenge, which he turned over to an undergraduate student at Georgia Tech named Erika Tyburski, was to create a cheap, fast, easy-to-use device that people with anemia from any cause could use to monitor their health.

Tyburski developed a chemical solution that would change color depending on the hemoglobin concentration in a sample drop of blood. The results correlated closely with the standard test. Another Georgia Tech student created an app that analyzes the results and transmits them. The AnemoCheck device has been tested in global health settings. Lam said it also could be used to warn patients with sickle cell anemia or with chronic anemia to seek medical attention. Lam recently founded Sanguina to commercialize this technology.

CELLSCOPE

Lam's third example capitalizes on the accelerometer that is now a standard smartphone component. His graduate student, David Myers, developed an app to track gross hand movements and used the phone to record the motion of a physician palpating a patient's abdomen. This trace can be sent to another phone and used to teach a patient to mimic the physician's motion. Like the AnemoCheck, the app could be used to help patients determine if they needed to see a doctor.

"With a few simple attachments and simple diagnostics, we came up with these three patient-operated smartphone applications," Lam says. "The potential is enormous."

Wilbur Lam, MD, PhD, is an assistant professor in the Department of Pediatrics at Emory University School of Medicine and the Wallace H. Coulter Department of Biomedical Engineering at the Georgia Institute of Technology and Emory University. He is also cofounder and chief medical officer at two startup companies, Cellscope and Sanguina. *Both companies received funding for their technologies from the FDA-sponsored Atlantic Pediatric Device Consortium, a collaboration between Children's Healthcare of Atlanta, Georgia Tech, Emory University, Virginia Commonwealth University and Children's Hospital of Richmond.*

POINT-OF-CARE TECHNOLOGIES: STRETCHABLE, WEARABLE ELECTRONICS FOR HUMAN HEALTH MONITORING AND HUMAN-MACHINE INTERFACES

WOON-HONG YEO

The highly sensitive and specialized devices that detect electrical activity in different parts of the body—the electrocardiogram (ECG), the electroencephalogram (EEG), and the electromyogram (EMG) to name just three—have revolutionized healthcare, but they all have a common and simple point of failure: the conformal interface between their electrodes and human skin. As Woon-Hong Yeo, an assistant professor in the Department of Mechanical and Nuclear Engineering and at the Center for Rehabilitation Science and Engineering at Virginia Commonwealth University (VCU), pointed out in beginning his presentation, "Human tissues and organs are soft, curvilinear, and stretchy. Conventional medical devices, often made of metal or plastic, are bulky, flat, and rigid. There is a fundamental mismatch between these materials in terms of mechanics and materials."

WOON-HONG YEO

In Yeo's view, this disjunction not only is responsible for inconclusive test results, but also dramatically constrains the application of these technologies to physicians' offices and bulky portable devices. To make electronic devices that share many of the characteristics of the tissues they touch, he founded the Bio-interfaced Nano Engineering Group at VCU and assembled an eclectic team of researchers that includes experts in mechanics, materials, electronics, nanoengineering, and signals processing.

In his presentation, Yeo highlighted the issues that arise when surface-mounted electrodes are employed with devices such as ECGs. Because the electrodes are rigid and flat while skin is curvilinear, technicians must fill the resulting gaps with an electrolyte gel to maintain signal quality. This gel evaporates over time, producing inconsistent electrical signals as impedance changes. "To address these issues," he said, "we developed a new form of skin-like electronics that mimics the mechanical and material properties of skin."

Yeo found that when his team reduced the total thickness of the electronic components to approximately 5 microns, they conformed perfectly to the contours of the skin. Reducing their thickness also decreased their weight, while increasing their adhesiveness. To provide stretchability, Yeo designed the electronics in an open-mesh, meandering pattern, rather than in a straight line. These devices can be built using conventional microfabrication techniques. "You can wear the ultrathin electronics on the skin for more than two weeks even with showers," Yeo said.

Yeo has shown that these wearable electronics could be used to monitor the wound healing process or provide long-term EEG monitoring when mounted on the ear and mastoid.

There are many other uses of such electronics besides monitoring. Yeo concluded his presentation by demonstrating how people with disabilities could use wearable electronics as part of a human-machine interface. Linked to an electromyograph, electrodes printed on the forearm could control a prosthetic device; a wearable device on the outer canthi of the eye, when connected to an electrooculograph could control a wheelchair. "There is no limit to potential applications," Yeo said, "No matter where you look, wearable electronics have the capacity to advance human healthcare significantly."

Woon-Hong Yeo, PhD, is an assistant professor in the Department of Mechanical and Nuclear Engineering (School of Engineering) and Center for Rehabilitation Science and Engineering (Schools of Medicine and Engineering) at Virginia Commonwealth University. His research focus is on the development of soft, wearable bioelectronics that can be used for human health monitoring and human-machine interfaces.

POINT-OF-CARE TECHNOLOGIES:
LOW-POWER WIRELESS SENSOR NODES
BENTON CALHOUN

The utility of long-term health monitoring is indisputable. Benton Calhoun, professor of electrical and computer engineering at the University of Virginia, began his presentation by highlighting the range of potential applications for body sensor nodes and wearables, from helping users better manage lifestyle choices to assisting researchers determine relationships between environmental toxins and health. "To realize these aspirations, we need a system that allows us to collect information over long periods of time and in many different places, around the body and on the body," he said. "But we are not there yet."

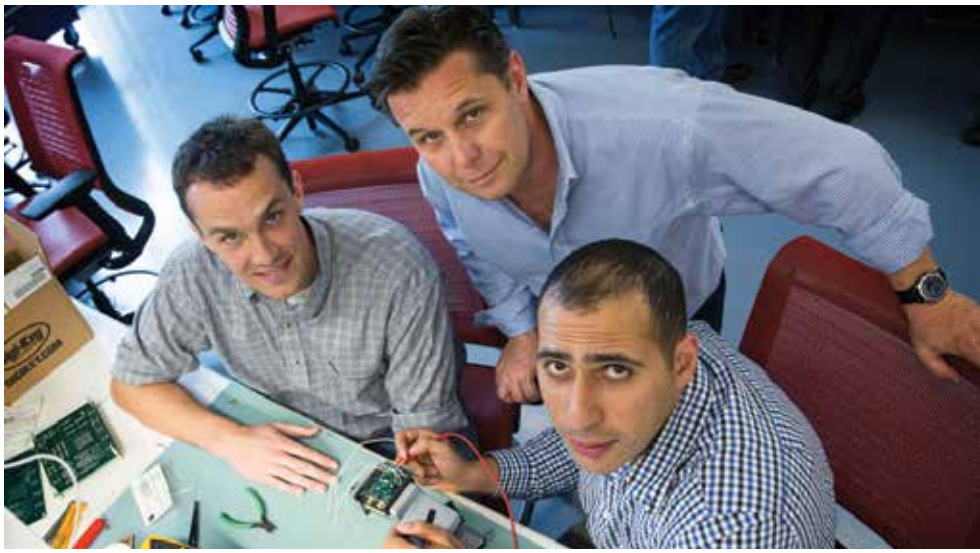
Calhoun noted that the body sensor nodes and wearables on the market suffer from several shortcomings, including size and limited functionality. For Calhoun, however, the biggest drawback is the amount of power they consume and the limits of their battery life. To extend their lifetime, the designers of these devices are forced to rely on such expedients as duty cycling or even turning them off for large fractions of time.

The ultimate solution, Calhoun asserted, is to create devices that can function on the energy they draw from the environment—a substantial challenge. Today's wearables consume power on the order of 10s to 100s of milliwatts when they are active. Energy harvesting in and around the body delivers 10s of microwatts per square centimeter, a number that is not projected to rise substantially anytime soon. Self-powered devices, Calhoun estimates, will require a thousand-fold reduction in energy consumption.

To convey the extent of the challenge, he made the following analogy: "If your car had a 1,000 times better energy efficiency, you would fill up the tank once during the lifetime of the vehicle," he said. "That's the kind of improvement we need."

Calhoun used another analogy to describe the process of designing these ultra-low-power devices. "The object," he said. "is to build a glider that can stay aloft forever without fuel. You can't get there by starting with a Boeing 747 and making incremental improvements. You have to develop a fundamentally different design."

This is a process that Calhoun's group at the University of Virginia and colleagues from University of Washington followed when designing a body sensor node that monitors heart health and transmits data using power generated from body heat. For this and subsequent generations of body sensor nodes, Calhoun begins by dividing the device into its four functional subsystems—energy harvesting and power management, sensing, processing, and wireless communication—and methodically rethinking each one.



DAN ADDISON

Ben Calhoun, PsiKick cofounder, CEO Brendan Richardson, and senior design engineer Yousef Shakhsheer with their ultra-low-power wireless, batteryless computer chip.

Calhoun reported that his group recently designed a system on a chip for body sensor nodes that is not only capable of bioelectric sensing but also can interface with accelerometers to monitor activity. The chip consumes less than 7 microwatts of power when broadcasting at 187 kbps.

Calhoun pointed out that these efforts and others like them are critical not just for better healthcare, but also for realizing the potential of other applications of the Internet of Things (IoT). PsiKick, the startup that he founded with David Wentzloff of the University of Michigan, is commercializing and refining ultra-low-power electronics. "If you envision 1 trillion sensors, each with a 10-year battery life, you will need to change 275 million batteries a year," he said. "You simply can't build the IoT with batteries. You need self-powered devices."

Benton Calhoun, PhD, is professor of electrical and computer engineering at the University of Virginia and cofounder and co-CTO of PsiKick, Inc., a company he formed to commercialize self-powered wireless sensors.

DIABETES TECHNOLOGY: SMARTPHONES AND THE UVA ARTIFICIAL PANCREAS PROJECT

BORIS KOVATCHEV

Measured in terms of human suffering and economic impact, diabetes is one of the most devastating chronic diseases. To convey the impact of the technology he is developing, Boris Kovatchev, founding director of the Center for Diabetes Technology at the University of Virginia, pointed out that emergency care accounts for 40 percent of the $245 billion spent annually on diabetes care in the United States. Technology currently undergoing clinical trials as part of the UVA Artificial Pancreas Project has the potential to eliminate diabetes emergencies, he said, while promising enhanced quality of life for those who suffer from this disease.

The Challenge for Diabetes Control

To set the stage for his presentation, Kovatchev sketched out the network of interactions that keep blood sugar within an acceptable range as an individual processes carbohydrates. "In type 1 diabetes, this network has broken down completely," he said. "In type 2 diabetes, it is deficient. As a result, blood sugar in patients with diabetes is elevated, increasing their risk for neuropathy, vascular complications, and a host of other conditions."

At the center of these interactions is insulin, which is produced by the pancreas. In the case of type 1 diabetes, patients use insulin injections to lower blood sugar, but this brings with it its own set of risks. Blood sugar levels must be maintained within a tight band. Too much insulin, and a person can become hypoglycemic and develop insulin shock. Not enough, and they can develop hyperglycemia and even lapse into a diabetic coma.

The Pace of Progress Accelerates

Kovatchev traced 50 years of steady but slow progress in the monitoring and regulation of insulin in diabetics. He noted two converging trends. The mathematical models of diabetes had become larger and more sophisticated, and portable insulin pumps and sensors had become smaller.

These trends converged in 2005. In that year, the Food and Drug Administration, the National Institutes of Health, and JDRF launched an artificial pancreas initiative. The goal was a closed-loop system, governed by control algorithms that would unite highly accurate continuous sensing of glucose levels with automatic dosing of insulin via an insulin pump.

UVA took up the challenge. Kovatchev knew that the pace of progress would be slowed by the need to test control algorithms in animal trials. To accelerate the artificial pancreas development, Kovatchev and colleagues at the University of Padova in Italy developed a large-scale computer simulation of diabetes. It encompasses 300 virtual subjects in three age groups. Each *in silico* subject is a complex entity based on 26 metabolic parameters that influence the production of insulin. In 2008, the FDA accepted the diabetes simulation as a substitute for animal trials in the preclinical testing of insulin treatments and artificial pancreas algorithms.

"This saved many years of development," Kovatchev said. "Once the simulator was approved, we were able to move from concept to inpatient clinical trials in just three months."

The Smartphone Breakthough

As early as 2009, Kovatchev and colleagues at UVA, Italy, and France perceived the advantage of using smartphones as the brains of this system. Early closed loop systems ran on laptop computers and had a web of wires connecting them to the patient's glucose sensor and insulin pump; in 2011, UVA introduced the Diabetes Assistant, the first artificial pancreas based on a smartphone. The smartphone receives data wirelessly from the glucose sensor every five minutes, computes the proper response based on control algorithms, and transmits instructions to the insulin pump. "The patient will get a microdose of insulin every five minutes as long as he or she needs it," Kovatchev said.

Pinpoint control was not the only advantage of this system. Its small size and the wireless connectivity made the artificial pancreas wearable, which in turn opened the way for 24-hour insulin regulation in active people. "It was a tremendous breakthrough," Kovatchev said.

From this point on, the pace of innovation increased dramatically. The length of the trials of smartphone-based systems grew from five nights to

Children enjoyed a weeklong ski and snowboard camp, thanks to the smartphone-based artificial pancreas that Boris Kovatchev and his team are developing.

UVA CENTER FOR DIABETES TECHNOLOGY

six months. Better yet, they moved from controlled environments into patients' homes and surroundings. This gave researchers the opportunity to test the Diabetes Assistant with children as well as adults, at night as well as during the day, and when they were active as well as sedentary. Each trial gave researchers an opportunity to further refine their algorithms.

Quickly, the data on the effectiveness of the artificial pancreas mounted up. "Our studies have accumulated approximately 193,000 hours of outpatient data, the equivalent of 22 years of testing," Kovatchev said. "We've shown that the artificial pancreas safely reduces the incidence of hypoglycemia without increasing average blood sugar levels."

For instance, in 2015, a six-month trial of the Diabetes Assistant showed that it kept blood sugar in the target range 77 percent of the time without any human intervention. A clinical trial conducted in January 2016 with a group of teenagers attending a weeklong ski and snowboard camp highlighted the ability of the artificial pancreas to improve quality of life for diabetes patients, and even allow them to engage in winter sports. For many of the children, the ski trip was the first time they were able to enjoy an extended stay away from home. "It changed their lives," Kovatchev said.

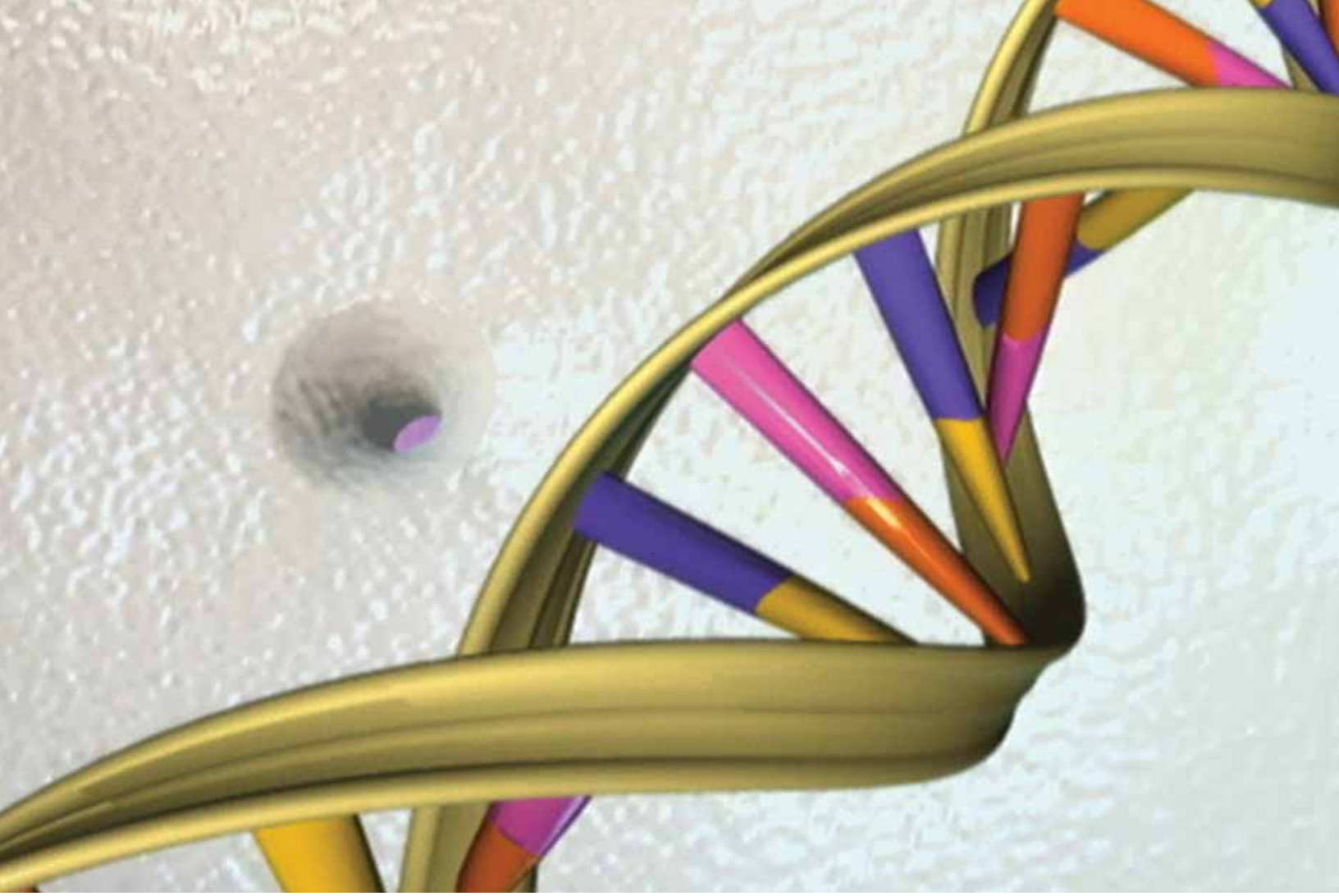
The Next Steps

UVA's Center for Diabetes Technology continues to refine its artificial pancreas algorithms. In 2016, Kovatchev reported, it launched an 11-month trial of its new Nightlight closed-loop algorithm, the first algorithm specifically engineered to adapt its mode of operation during the course of a night. The Nightlight algorithm mitigates after-dinner high blood sugar levels, keeps the patient safe from hypoglycemia while sleeping, and slides to a target morning glucose level of 120mg/dl, resetting his or her metabolic state back to normal for the start of a new day.

As a result, the artificial pancreas has reached a pivotal stage in its development. Kovatchev is the principal investigator for the International Diabetes Closed Loop Trial, a $12.7 million initiative involving institutions in the United States and Europe. Kovatchev expects the study to be complete in 2018. "If we are successful," he said, "the next step will be to move this technology to industry, where it can be commercialized." Kovatchev co-founded TypeZero Technologies, a startup in Charlottesville, to move artificial pancreas technology into the market as rapidly as possible.

Kovatchev has already begun work on the next-generation artificial pancreas. A multisensor system, it would track heart rate, physical activity, and other variables that affect blood glucose and control it using a multihormone system that includes insulin. Kovatchev has secured NIH funding to conduct research in both areas, with results available by 2019 and 2020.

Boris Kovatchev, PhD, is founding director of the Center for Diabetes Technology at the University of Virginia, a professor at the UVA School of Medicine and an adjunct professor at the School of Engineering and Applied Science. He is currently the principal investigator of several large clinical trials related to closed-loop control and advisory systems for diabetes.



BIOMARKERS IN THE NEW FIELDS OF MEDICINE

ROBERT CALIFF

If we are to realize the future of smart and connected health, we must have effective biomarkers. "If you have reliable biomarkers, your likelihood of developing a successful therapy is much higher than if you don't," Robert Califf said in beginning his presentation. "Almost every drug or biologic that is developed targets a process that produces a biomarker that can be measured."

Califf is in a position to know. A highly regarded cardiologist and researcher, he was at the time of the VASEM Summit the commissioner of the U.S. Food and Drug Administration (FDA). In his talk, Califf pointed to a number of impediments to achieving reliable biomarkers and highlighted FDA initiatives to overcome them.

The first issue, Califf pointed out, is that, although everyone takes the meaning of terms like *biomarker*, *surrogate endpoints*, and *clinical outcome assessments* for granted, there are no consensus definitions. Califf recalled attending a meeting of the FDA-NIH Joint Leadership Council on biomarkers when he first joined the FDA in 2015 only to observe the conversation devolving into an argument about the meaning of *surrogate endpoint*. "We looked at each other and realized that even among the leaders of these two agencies, we didn't agree on fundamental definitions of crucial terminology." Califf worried that misunderstandings would deter progress in developing medical products and potentially compromise efficiency in achieving public health benefits.

The council formed a working group to address this issue. Its challenge was to settle upon definitions that were broad enough to be used by diverse communities, including biomedical scientists,

NATIONAL INSTITUTES OF HEALTH

translational researchers, clinical researchers, medical product developers, and clinicians, and also across diverse types of products. The result was the Biomarkers, Endpoints, and other Tools (BEST) Resource, now available on the National Center for Biotechnology Information's bookshelf.

Biomarkers in Context

Califf emphasized that contextual considerations are critical when using biomarkers. "Biomarkers change depending on the purpose and the context in which you are using them," Califf said. This could include their setting—basic research, drug development, and clinical practice. It could include their immediate purpose—there are diagnostic biomarkers, predictive biomarkers, safety biomarkers, and more. And it could also include the patient population in which they are applied. A biomarker that is useful for a disease in a specific population may be useless in another. And even within the same setting, biomarkers can vary. Some types of biomarkers provide insight on the genetic and metabolic characteristics that alter patients' responsiveness to particular drugs, and others give insight into whether drugs in development are likely to work.

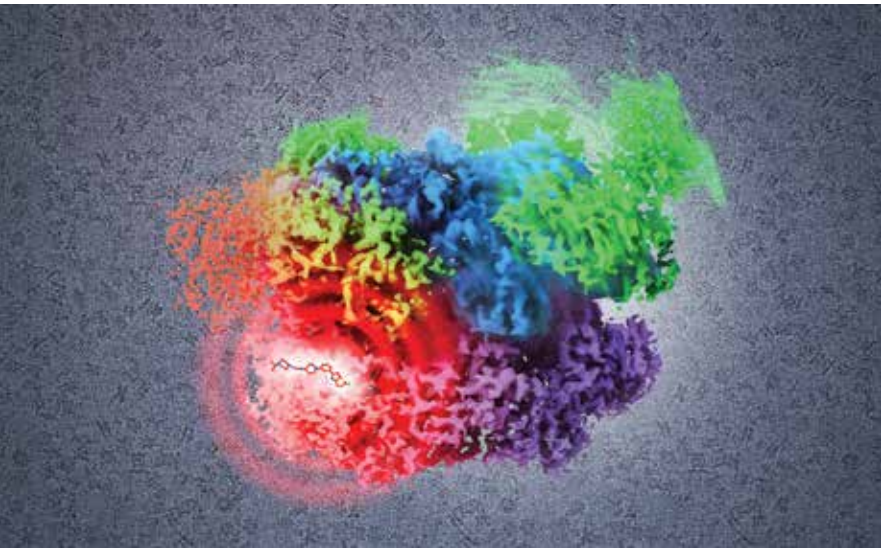
The FDA established a Biomarker Qualification Program to support the drug development process by making it easier for industry to employ appropriate biomarkers. Developers can request regulatory qualification of a biomarker for a particular context of use in drug development. Once a biomarker is qualified, it can be used in any drug development program under the context for which it obtained qualification.

This is not to underestimate the difficulty of finding reliable biomarkers for drug discovery. Califf noted that drug development is a lot more like soccer than it is like basketball. "You expect good basketball players to make 35 to 45 percent of their shots," Califf said. "In soccer, there are a lots of shots on goal, but only a few go in." He noted that despite dramatic advances in medical science, the latest data continue to indicate that the vast majority of drugs entered into early-phase human testing will not make it to market. This is due to a complex combination of failure to demonstrate efficacy, unexpected toxicity, and difficulty with manufacturing. "If we could figure out how to find more powerful biomarkers, we might be able to score more goals," he said.

The Precision Medicine Initiative

Califf believes that big data projects like the Precision Medicine Initiative, which is being led by Google's Verily and the Vanderbilt University Medical Center along with other collaborators, suggest one way to achieve this. It hopes to enlist 1 million participants by 2019. In the past, researchers occasionally discovered individual biomarkers that, like systolic blood pressure or cholesterol, were unusually valuable. Going forward, biomarkers will more often be multidimensional. One challenge for the initiative is to analyze a wide range of disparate data—combining things like geospatial data, medical imaging, self-reports, and wearable history—for large population groups to discover biomarkers for chronic complex diseases. Machine learning will be a key technology in accomplishing this.

Determining these groups will also be critical. "The old way was to measure the individual because that's all we could do," he said. "The new way is to identify and validate important subsets using large denominators." Califf quoted Hippocrates' observation that "it is more important to know which person has a disease than what sort of a disease a person has." "We'll see," Califf said, "if that is true over time."



NATIONAL INSTITUTES OF HEALTH

Robert Califf, MD, MACC, was the commissioner of the U.S. Food and Drug Administration. Prior to joining the FDA, Dr. Califf, a cardiologist, was a professor of medicine and vice chancellor for clinical and translational research at Duke University.

Roundtable Discussion

ON HEALTH ECONOMICS

BARBARA D. BOYAN, JEFFREY GALLAGHER, JUSTIN KLEIN, MICHAEL W. WELLMAN

Barbara D. Boyan

Barbara D. Boyan, the summit organizer, brought together an expert panel to provide perspectives on the challenges that Virginia entrepreneurs face as they seek to move medical technology into the marketplace. This includes making sure their technology is secure, that they have access to venture capital, and that they are taking advantage of Commonwealth efforts to stimulate the innovation economy. "Time is always critical for entrepreneurs," Boyan said. "When technology moves into the commercial sector, it has to be adopted quickly and generate revenue for the individuals who back it."

Barbara Boyan, PhD, holder of the Alice T. and William H. Goodwin Jr. Chair of Biomedical Engineering, is dean of the School of Engineering at Virginia Commonwealth University. She is a member of the National Academy of Engineering and a Fellow of the American Association for the Advancement of Science. In 2017, she was inducted into the National Academy of Inventors. Dr. Boyan has co-founded medical device companies in Texas, Georgia, and most recently, in Virginia.

Jeffrey Gallagher

"From the point of view of bioscience commercialization, you need an innovative idea, scientific and business talent, and money," noted Jeffrey Gallagher in prefacing his remarks. "We have them all in Virginia, but unlike places like Boston, they are not concentrated. They are spread out across the Commonwealth."

One of the roles of the association Gallagher leads, Virginia Bio, is to create statewide links among these three elements and to further their development in localities, like Charlottesville, where they are all present. "At Virginia Bio, our focus goes beyond technology," Gallagher says. "We work to create the social systems needed to move that technology into the marketplace."

Gallagher pointed to a number of factors that are making it easier for his organization to build these relationships, especially in healthcare technology, and that can help healthcare startups in Virginia pursue commercialization more effectively.

The first is the rise of large healthcare systems like Inova, Sentara, and UVA, which have created investment funds to promote new healthcare technologies. Gallagher pointed out that to be successful, healthcare systems of this scale cannot content themselves with consuming innovation. They must drive it. He estimated that Virginia healthcare systems have the capacity to invest approximately $500 million in healthcare startups.

The second is the convergence of healthcare with data science, which has the potential to revolutionize the treatment of disease. Virginia has outstanding strengths in data science, both in the private sector as well as at many of the state's universities. "It is my task," Gallagher said, "to encourage our data scientists to focus on biosciences."

Finally, Gallagher noted there have been recent changes in public policy in Virginia that have created incentives for universities and corporations to work more closely on projects that could lead to commercialization. This includes establishment of the Virginia Biosciences Health Research Corporation, which provides grant funding, the Virginia Research Investment Fund, and the Go Virginia initiative. Gallagher also pointed to the rise of philanthropic investment capital in the state.

"Taken together, there is a lot of interest in mobilizing the resources needed to capture our potential as a biotechnology leader," he said. "At Virginia Bio, we try to communicate that potential and help unleash that funding."

Jeffrey Gallagher, JD, LLM, is CEO of the Virginia Biotechnology Association, the premier statewide nonprofit trade association representing the life sciences industries.

Justin Klein

As an experienced venture capitalist, Justin Klein brought to the panel his perspectives on the characteristics that set healthcare apart from other areas of technology investment and how these characteristics creates opportunities and pitfalls for startups and for investors in these startups.

"Technology investors and entrepreneurs that we work with look at healthcare as this wide open region of opportunity, where IT solutions that worked well in other markets like financial services or consumer markets can easily be adapted to the healthcare setting," he said. "We have found this is definitely not the case. The needs of stakeholders in healthcare are far different, the standards are different, and the approach to technology is culturally very different."

Klein cited a number of examples of these differences. Unlike other areas of technology, healthcare is highly regulated. Healthcare products must go through an exacting FDA approval process, but even approved products are not guaranteed widespread adoption unless public and private payers determine that they are eligible for reimbursement.

Klein also noted that the transition under way in healthcare from episodic acute care to actively managed care will necessarily require patients to more proactively manage their health. Although the benefits for patients of active management are clear, efforts to convince them to use devices that connect them to their providers or help them manage their conditions run up against cultural barriers. "People who don't think twice about spending $10 a month for a streaming service will hesitate to pay the same amount for an app that helps them manage their diabetes," Klein says. "The adoption curve for healthcare technologies is very different from other areas."

These factors make it difficult for investors like Klein, who has a 10-year horizon, to know when to invest. "One of the hardest things I contend with is identifying where we are in the investment spectrum," he said. "Determining when should we invest to see value realized—not too early or too late—is not a trivial issue."

Justin Klein, MD, JD, is a partner in the Washington, DC, office of New Enterprise Associates (NEA), a large venture capital firm. He focuses on medical device, healthcare technology, and biopharmaceutical company investments.

Michael W. Wellman

Michael W. Wellman's background in mathematics and his long history with connected devices—he was part of teams that developed early web browsers, Wi-Fi products, and other networking technologies—gives him a unique perspective on the evolution of cybersecurity. "For years, hackers have concentrated on personal privacy and financial technology," he said. "As defenses in these areas have improved, they have switched to health data."

There are a number of reasons for this, Wellman said. From a cultural point of view, healthcare organizations are much more focused on treating patients than securing data and, as a consequence, have not invested adequately in security. In addition, the value of health records on the dark Internet has risen dramatically as thieves have discovered a variety of uses for them including creating fraudulent prescriptions for drugs that can be resold illegally. Furthermore, health data have a much longer shelf life—years may go by before the breach is detected—and once they are discovered, remedies are difficult to impose. A person's health record—the details of a medical condition or a mother's maiden name—cannot be replaced the way a credit card can.

Wellman advocated a two-part approach to bolster security in health technology. The first step is to make the best use of existing defenses by training staff to follow accepted security procedures and to inventory network equipment to ensure that critical software is up to date and includes the latest security patches. The second is for medical device software developers to apply state-of-the-art cryptographic techniques of the sort that Wellman's company, Virgil Security, provides. These techniques include authentication without passwords, end-to-end encryption of data both at rest and in transit, and cryptographic verification of data, devices, and identities. Virgil packages these technologies as software building blocks that developers can insert easily into their products.

"We realize that no one chooses to invest in or purchases a particular medical technology simply because it is the most secure," Wellman said. "It's because it's better, easier to use, or less expensive—and also secure. We make it possible for security to be a matter of course."

Michael W. Wellman is the CEO and cofounder of Virgil Security, Inc., which creates cryptographic building blocks for software developers enabling them to quickly and easily add passwordless authentication, encryption, and other cryptographic functionality to their devices.

VIRGINIA ACADEMY OF SCIENCE, ENGINEERING, AND MEDICINE

The Virginia Academy of Science, Engineering, and Medicine (VASEM) began in 2013 as a nonpartisan resource for independent expertise to help with science and technology policy matters facing the Commonwealth. VASEM is comprised of elected members of the National Academy of Science, National Academy of Engineering and the National Academy of Medicine (formerly Institute of Medicine) that reside or work in Virginia.

Our network of experts provides rigorous analytical and scientific support to inform policy discussions that are critical to our future. We provide a collective rigor and objectivity to the state that no single institution can achieve on its own.

VASEM considers requests for scientific analysis, technical evaluations, and analysis of technical policy issues submitted General Assembly or other appropriate governmental or nongovernmental organizations.

Andrew Densmore (executive director), Robert Kahn, Florence Haseltine, X.J. Meng, James Aylor (secretary/treasurer), Patricia Dove, Anita Jones, Thomas Young, Lester Lyles.
Not pictured: Senator Mark Warner (honorary chair), Barbara Boyan, Joe Campbell, Robert Carey, P.J. Coney, Antonio Elias.

VASEM MEMBERS

Faye Glenn Abdellah, NAM, *Uniformed Services University of Health Sciences*

Edward Aldridge, Jr., NAE, *U.S. Department of Defense*

John Anderson, NAE, *Howard Hughes Medical Institute*

Norman Anderson, NAM, *American Psychological Association*

Bruce Baker, NAS, *Howard Hughes Medical Institute*

Craig Benson, NAE, *University of Virginia*

Toby Berger, NAE, *University of Virginia*

Peter Bethell, NAE, *Cardno MM&A*

Eric Betzig, NAS, *Howard Hughes Medical Institute*

Enriqueta Bond, NAM, *Burroughs Wellcome Fund*

Richard Bonnie, NAM, *University of Virginia*

Jay Boris, NAE, *U.S. Naval Research Laboratory*

Dushan Boroyevich, NAE, *Virginia Tech*

**Barbara Boyan, NAE, *Virginia Commonwealth University*

L.D. Britt, *Eastern Virginia Medical School*

John Bryant, NAM

Sheila Burke, NAM, *Howard Hughes Medical Institute*

Wesley Bush, NAE, *Northrop Grumman Corporation*

Dennis Bushnell, NAE, *NASA Langley Research Center*

Harry Cain II, NAM, *Blue Cross Blue Shield Association, Retired*

**Joe Campbell, NAE, *University of Virginia*

**Robert M. Carey, NAM, *University of Virginia*

Vinton Cerf, NAE, *Google, Inc.*

Douglas Chapin, NAE, *MPR Associates, Inc.*

Roger Chevalier, NAS, *University of Virginia*

James Childress, NAM, *University of Virginia*

Rita Chow, NAM, *National Council on Aging*

Robert Clagett, NAE

**PonJola Coney, NAM, *Virginia Commonwealth University*

Henry Cox, NAE, *Lockheed Martin Corporation*

F. Fleming Crim, NAS, *University of Wisconsin-Madison*

Lance Davis, NAE

Don Detmer, NAM, *University of Virginia*

John Dorning, NAE, *University of Virginia*

*Patricia Dove, NAS, *Virginia Tech*

James Duncan, NAE, *Virginia Tech*

Lloyd Duscha, NAE

**Antonio Elias, NAE, *Orbital Sciences Corporation*

Robert Epstein, NAM, *University of Virginia*

Stephanie Ferguson, NAM, *International Council of Nurses*

James Frank, NAE, *University of Maryland*

William Friend, NAE, *Bechtel Group, Inc.*

Gerald Galloway, NAE, *University of Maryland*

Jacques Gansler, NAE, *University of Maryland*

Nicholas Garber, NAE, *University of Virginia*

Naomi (Lynn) Gerber, NAM, *George Mason University*

Thomas Giallorenzi, NAE, *Naval Research Laboratory*

Richard Guerrant, NAM, *University of Virginia*

**Florence Haseltine, NAM, *Haseltine Systems*

Henry Hatch, NAE

Ulrike Heberlein, NAS, *Howard Hughes Medical Institute*

John Holdren, NAS/NAE, *Executive Office of the President of the U.S.*

Barry Horowitz, NAE, *University of Virginia*

James Hubbard, NAE, *National League for Nursing*

John Hudson, NAE, *University of Virginia*

Betsy Humphreys, NAM, *National Institutes of Health*

Peter Hutt, NAM, *Covington & Burling LLP*

Ada Jacox, NAM, *Athena Vineyards*

Elaine Jaffe, NAM, *National Cancer Institute*

Stuart Jessup, NAE, *Naval Surface Warfare Center*

**Anita Jones, NAE, *University of Virginia*

**Robert Kahn, NAE/NAS, *Corporation for National Research Initiatives*

Paul Kaminski, NAE, *Technovation, Inc.*

Isabella Karle, NAS, *Naval Research Laboratory*

Kenneth Kellermann, NAS, *National Radio Astronomy Observatory*

Kenneth Kendler, NAM, *Virginia Commonwealth University*

Paul Kern, NAE, *The Cohen Group*

Richard Knapp, NAM

Leonard Konikow, NAE, *US Geological Survey*

Frederick Krambeck, NAE, *ReacTech Inc.*

Judith Lean, NAS, *Naval Research Laboratory*

Fred Lee, NAE, *Virginia Tech*

Allen Lichter, NAM, *American Society of Clinical Oncology*

Jennifer Lippincott-Schwartz, NAM, *University of Wisconsin-Madison; University of Virginia School of Law*

Raymond Loehr, NAE, *University of Texas*

Andrew Lovinger, NAE, *National Science Foundation*

Gerald Luttrell, NAE, *Virginia Tech*

**Lester Lyles, NAE, *Aeronautics and Space Engineering Board*

Malcolm MacKinnon, NAE, *USN Retired*

David Maddox, NAE, *National Academy Board on Army Science & Technology (BAST)*

Beverly Malone, NAM, *National League for Nursing*

Gerald Mandell, NAM, *University of Virginia*

Robert McCale, NAE, *National Science Foundation*

Kishor Mehta, NAE, *National Science Foundation*

** Xiang-Jin Meng, NAS, *Howard Hughes Medical Institute*

Richard Merrill, NAM, *University of Virginia*

Richard Meserve, NAE, *Carnegie Institution for Science*

Martin Mikulas, Jr., NAE, *University of Colorado Boulder*

James Mitchell, NAS/NAE, *Virginia Tech*

John Monahan, NAM, *University of Virginia School of Law*

Arthur Money, NAE, *U.S. Department of Defense*

Charles Moorman, NAE, *University of Maryland*

Ferid Murad, NAM/NAS, *The George Washington University*

Thomas Murray, NAE, *Virginia Tech*

David Nash, NAE, *Dave Nash and Associates, LLC*

Alan R. Nelson, NAM, *ACP*

John Niederhuber, NAM, *Inova Fairfax Hospital*

James Nuckolls, NAM, *Carilion Health System*

Kenneth Olden, NAM, *Environmental Protection Agency*

Malcolm O'Neill, NAE, *United States Army*

Elaine Oran, NAE, *University of Maryland*

Joseph Ornato, NAM, *Virginia Commonwealth University*

Hilliard Paige, NAE, *University of Virginia*

Sorab Panday, NAE, *GSI Environmental*

Arun Phadke, NAE, *Virginia Tech*

Robert Phillips, NAM, *American Board of Family Medicine*

Dolores Piperno, NAS, *Smithsonian Institution*

Stephen Plog, NAS, *University of Virginia*

John Edward Porter, NAM/NAS, *Hogan Lovells U.S., LLP*

Arati Prabhakar, NAE, *Hogan Lovells U.S., LLP*

Charles Pryor, Jr., NAE, *Urenco USA*

Bhakta Rath, NAE, *Naval Research Laboratory*

Lynn Riddiford, NAS, *Howard Hughes Medical Institute*

Morton Roberts, NAS, *National Radio Astronomy Observatory*

Alton Romig, NAE, *National Academy of Engineering*

Sara Rosenbaum, NAM, *The George Washington University School of Public Health and Health Services*

Gerald Rubin, NAS/NAM, *Janelia Farm, Howard Hughes Medical Institute*

Eugene Sakshaug, NAE

Robert Schafrik, NAE, *GE Aviation*

Hanif Sherali, NAE, *Virginia Tech*

Bruce Smith, NAS, *Smithsonian Institution*

Edgar Starke, NAE, *University of Virginia, Retired*

John Stenbit, NAE

Timothy Stolzfus-Jost, NAM, *Washington and Lee University*

Lawrence Stone, NAE, *Metron, Inc.*

Jerome Strauss, NAM, *Virginia Commonwealth University*

Stanley Suboleski, NAE, *Evan Energy Investments*

Karel Svoboda, NAS, *Howard Hughes Medical Institute*

David Thompson, NAE, *Orbital Sciences Corporation*

James Turner, Jr., NAE, *General Dynamics Corporation*

Harry Van Trees, NAE, *George Mason University*

Walter Wadlington, NAM, *University of Virginia School of Law*

Bailus Walker, NAM, *Howard University*

George Watkins, NAS, *Lehigh University*

Peter Wilhelm, NAE, *Naval Research Laboratory*

Donald Winter, NAE

Maurice Wood, NAM, *Virginia Commonwealth University Department of Family Medicine*

Steven Woolf, NAM, *Virginia Commonwealth University*

Mary Woolley, NAM, *Research!America*

Carl Wu, NAM/NAS, *Howard Hughes Medical Institute*

William Wulf, NAE, *University of Virginia*

Roe-Hoan Yoon, NAE, *Virginia Tech*

**Thomas Young, NAE

*President **Board Member

VASEM
2920 West Broad Street
Suite 120
Richmond, VA 23230
www.VASEM.org