

APPLIED SCIENCES AND ENGINEERING

Biomedical devices go wild

In their studies of grand challenges for the global community in the 21st century, the National Academy of Engineering concluded that advances in “...the acquisition, management, and use of information in health...” will greatly enhance the quality and efficiency of medical care and our ability to respond to public health emergencies. Decisions and preventative measures informed by real-time data and associated analytics will only become more urgent as global age demographics shift, particularly as the proportion of people over 65 rises to near 17% by 2050. Emerging classes of body-integrated electronic sensors offer unique capabilities for collecting and distributing continuous, clinical-quality health information and thereby improving the delivery of treatments to the elderly and other vulnerable populations, regardless of their location. These new, futuristic bioelectronic devices serve as the foundations for a range of powerful tools and microsystems that seamlessly and non-invasively integrate with the skin, in an imperceptible fashion. Integrated technologies supported by bioelectronic platforms will automatically capture and share critical physiological data with physicians, health care officials, family members, and care providers who, in turn, can use the information to inform and improve health care at individual, community, and global levels.

Recent progress in this area was highlighted at a 2018 AAAS symposium entitled “Biomedical Devices in Service to Society.” There, researchers discussed new concepts and designs for electronic devices that have the potential to revolutionize the way that we sense, record, and analyze essential parameters of human health, including traditional vital signs as well as patterns of motion, sounds of body processes, and biochemical signatures in sweat, tears, and saliva. Speakers described studies of new skin-interfaced electronic sensors that provide data on patients recovering from stroke, managing symptoms of Parkinson’s disease, or suffering from atrial fibrillation. Other work focused on the development of epidermal electronic systems as skin-like apparatuses that allow intimate integration onto nearly any surface of the body, without irritation or discomfort. The unusual mechanical properties of these technologies are particularly important: Their miniaturized, lightweight construction and intimate skin interface eliminates motion artifacts and allows precise collection of biophysical data in natural contexts, including those outside clinical or laboratory settings. These essential characteristics differ markedly from those of conventional, wafer-based integrated circuits and open totally new opportunities for research and application. In fact, such devices are already being validated through field studies in major hospitals, rehabilitation clinics,

military settings, and in professional and collegiate sports.

Innovations in biomedical device design such as these are increasingly abundant. Some resemble tattoos or thin adhesive bandages adhered to the skin, while others take the form of soft conductive gels that create high-quality electrical-skin interfaces, able to collect accurate recordings of cardiac, brain, and muscle activity. Epidermal sensors of mechano-acoustic signals gently mounted on the base of the neck allow precise measurements of speech and swallowing to facilitate rehabilitation protocols for patients suffering from aphasia and/or dysphagia. Soft, thin microfluidic networks bonded to skin can capture, store, and analyze the chemical constituents in minute volumes of sweat. These biomedical laminates provide a real-time non-invasive method for assessing body chemistry in ways that could complement traditional blood analysis techniques, with the capacity for real-time visual read-out through integrated displays that present the information directly and intuitively to users.

New bioelectronic designs extend beyond skin-mounted appliances to implanted, programmable devices with unique modes of operation, including those that follow from their ability to bypass the blood-brain barrier. Such systems will interface directly with internal organs, allowing targeted, personalized, programmed drug delivery, and, in turn, dramatically reduced possibilities for drug toxicity and/or side effects. Related bioelectronic implants will deliver electrical stimulation to the heart and brain to treat arrhythmias and cognitive disorders in ways not possible today. Such “bioelectronic medicines” will complement pharmaceuticals in the treatment of disease and healing processes and may one day replace many of their functions.

These technologies will also yield high-quality “big data” related to natural body processes, including those that occur during the full range of daily activities. This type of information, collected from individuals and across populations, may help to transform and extend our understanding of human systems and physiology. Future embodiments will support unprecedented levels of device autonomy, leveraging advances in deep learning algorithms and artificial intelligence-based diagnostics, some of which can already outperform highly trained physicians for certain tasks. Aligning with the sensibilities of users and regulators, such devices will also integrate secure communication protocols, advanced encryption schemes, and safe storage mechanisms to ensure sustained privacy and individualized use of personal and aggregated information.

The examples of new technologies featured in the AAAS symposium are representative of the impressive



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progress in this new domain of interdisciplinary study, where basic research in engineering science is establishing the foundations for groundbreaking innovations in medicine and human health care. Just as the field of consumer electronics developed rapidly in response to the public's voracious appetite for devices to improve productivity, communications, and entertainment, so are similar dynamics propelling advances in biomedical device design for health care, sports, and military applications. Future advances will rely on the melding of technology with biology in ways not yet imagined. The associated areas of scientific challenge are diverse and significant, ranging from materials and manufacturing science, to sensor design and power supply, to data communication, analysis, and secu-

urity. Although testing and commercialization of early tools and products are already well underway, interdisciplinary research at the crossroads of invention, material design, and system innovation will continue to play a critically important role in the development of technologies that can accelerate global efforts to confront and conquer growing challenges in global health.

– **John Rogers, George Malliaras, Takao Someya**

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