Study describes five cutting-edge advances in biomedical engineering

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IEEE, the world's largest technical professional organization dedicated to advancing technology for humanity, and the IEEE Engineering in Medicine and Biology Society (IEEE EMBS), today published a detailed position paper on the field of biomedical engineering titled "Grand Challenges at the Interface of Engineering and Medicine."

The paper, published in the *IEEE Open Journal of Engineering in Medicine and Biology* (*IEEE OJEMB*), was written by a consortium of 50 researchers from 34 universities around the world and laid the foundation for a concerted worldwide effort to achieve technological and medical breakthroughs.

"What we've accomplished here will serve as a roadmap for groundbreaking research to transform the landscape of medicine in the coming decade," said Dr. Michael Miller, senior author of the paper and professor and director of the Department of Biomedical Engineering at Johns Hopkins University. "The outcomes of the task force, featuring significant research and training opportunities, are poised to resonate in engineering and medicine for decades to come."

The position paper was the result of a two-day workshop organized by IEEE EMBS and the Department of Biomedical Engineering at Johns Hopkins University and the Department of Bioengineering at the University of California San Diego. Through the course of the workshop, the researchers identified five primary medical challenges that have yet to be addressed, but, by solving them with advanced biomedical engineering approaches, can greatly improve human health.

One of the participants in the workshop was Paolo Bonato, Ph.D., director of the Motion Analysis Laboratory at Spaulding Rehabilitation, a member of Mass General Brigham, and associate professor of Physical Medicine and Rehabilitation at Harvard Medical School.

"This manuscript is a unique contribution by 50 key players in the field of biomedical engineering highlighting areas of future technical developments that are expected to enable advanced precision medicine interventions," said Bonato.

"The future of medicine is expected to heavily rely on advances in biology and technology, and we can achieve this goal by collecting an unprecedented amount of high-quality data that will inform digital twin models and, hence, develop patient-specific therapy plans or even predict and prevent the development of diseases."

"This paper represents a major milestone in the advancement of biomedical engineering, which could only have been achieved through close collaboration rather than the work of many siloed individuals," added consortium member Dr. Metin Akay, founding chair of the Biomedical Engineering Department at the University of Houston and Ambassador of IEEE EMBS.

"We have a shared commitment to advancing patient-centric technologies, and health care efficacy and accessibility—which extends beyond academic institutions—and elevating health care quality, reducing costs and improving lives worldwide."

By focusing on these five medical challenges facing biomedical engineering, the consortium has laid out a roadmap for future research and funding:

Bridging precision engineering and precision medicine for personalized physiology avatars

In an increasingly digital age, we have technologies that gather immense amounts of data on patients, which clinicians can add to or pull from. Making use of this data to develop accurate models of physiology, called "avatars"—which take into account multimodal measurements and comorbidities, concomitant medications, potential risks, and costs—can bridge individual patient data to hyper-personalized care, diagnosis, risk prediction, and treatment.

Advanced technologies, such as wearable sensors and digital twins, can provide the basis of a solution to this challenge.

The pursuit of on-demand tissue and organ engineering for human health

Tissue engineering is entering a pivotal period in which developing tissues and organs on demand, either as permanent or temporary implants, is becoming a reality.

To shepherd the growth of this modality, key advancements in stem cell engineering and manufacturing—along with ancillary technologies such as gene editing—are required. Other forms of stem cell tools, such as organ-on-a-chip technology, can soon be built using a patient's own cells and can make personalized predictions and serve as "avatars."

Revolutionizing neuroscience using artificial intelligence (AI) to engineer advanced brain-interface systems

Using AI, we have the opportunity to analyze the various states of the brain through everyday situations and real-world functioning to pinpoint pathological brain function noninvasively. Creating technology that does this is a monumental task, but one that is increasingly possible. Brain prosthetics, which supplement, replace, or augment functions, can relieve the disease burden caused by neurological conditions.

Additionally, AI modeling of brain anatomy, physiology, and behavior, along with the synthesis of neural organoids, can unravel the complexities of the brain and bring us closer to understanding and treating these diseases.

Engineering the immune system for health and wellness

With a heightened understanding of the fundamental science governing the immune system, we can strategically make use of the immune system to redesign human cells as therapeutic and medically invaluable technologies.

The application of immunotherapy in cancer treatment provides evidence of the integration of engineering principles with innovations in vaccines, genome, epigenome, and protein engineering, along with advancements in nanomedicine technology, functional genomics, and synthetic transcriptional control.

Designing and engineering genomes for organism repurposing and genomic perturbations>

Despite the rapid advances in genomics in the past few decades, there are obstacles remaining in our ability to engineer genomic DNA. Understanding the design principles of the human genome and its activity can help us create solutions to many different diseases that involve engineering new functionality into human cells, effectively leveraging the epigenome and transcriptome, and building new cell-based therapeutics.

Beyond that, there are still major hurdles in gene delivery methods for in vivo gene engineering, in which we see biomedical engineering as a component of the solution to this problem.

"These grand challenges offer unique opportunities that can transform the practice of engineering and medicine," remarked Dr. Shankar Subramaniam, lead author of the task force, distinguished professor of Shu Chien-Gene Lay Department of Bioengineering at the University of California San Diego and past President of IEEE EMBS.

"Innovations in the form of multi-scale sensors and devices, creation of humanoid avatars, and the development of exceptionally realistic predictive models driven by AI can radically change our lifestyles and response to pathologies. Institutions can revolutionize education in biomedical and engineering, training the greatest minds to engage in the most important problem of all times—human health."

More information: Shankar Subramaniam et al, Grand Challenges at the Interface of Engineering and Medicine, *IEEE Open Journal of Engineering in Medicine and Biology* (2024). DOI: 10.1109/OJEMB.2024.3351717

Provided by Mass General Brigham