GLOBAL HEALTH

Beyond Disease, How Biomedical Engineering Can Improve Global Health

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Biomedical engineering tools can be harnessed to address some of the world's most challenging nondisease–focused problems.

Biomedical engineers have a long history of applying innovative tools and technologies, such as organotypic tissue models and multimodal imaging, to uncover new mechanisms of disease and, in turn, improve human health. But human—and global—health requires more than just a disease focus; challenges in providing clean water, sustaining food production, and finding new and clean sources of energy affect the global population.

The World Health Organization (WHO) has documented that water quality, food security, environment, and energy are extremely important to global health (*1*) and can be linked to some of the leading causes of death worldwide. Lower respiratory tract infections and chronic obstructive pulmonary disease are associated with deleterious environmental conditions, such as air quality, and diarrheal diseases can result from contaminated food and water (Fig. 1). The top cause of mortality in low-income countries is lower respiratory tract infections, followed closely by diarrheal diseases (also present in middle-income countries) and protein energy malnutrition, linked to food security (Fig. 1).

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Biomedical engineers have the distinct opportunity to improve global health. Here, we highlight innovative technologies and health-knowledge gaps to show how engineering can go beyond human disease to tackle some of the WHO's most pressing challenges: Water, food, and energy.

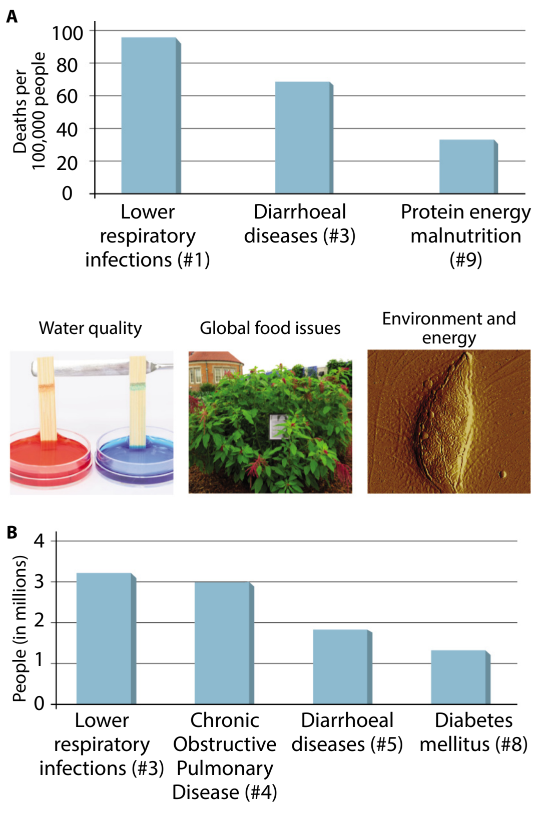

Fig. 1. Mortality versus income. Data from the WHO show leading causes of death per 100,000 people by income status (*1*). (**A**) Leading causes of deaths in low income countries. (**B**) Leading causes of deaths worldwide. Air quality affects residents worldwide, whereas water and food quality account for more deaths in lower-income. Biomedical engineering approaches to solving food, water, and environmental and energy challenges are critical for improving health in lower-income countries. Cause of death categories that were not in the top 10 for each income category are not represented in the chart. [Photo credits (L-R): C.-M. Kuan, M. B. Wilson, K. Warren]

WATER QUALITY ASSURED

The role of water in maintaining the health of humans and animals is obvious, but reliable sources and the quality of water remain major concerns in many parts of the world (*2*). Many countries need cost-effective, energy-efficient, low-impact, and robust technologies to monitor and to improve water quality through purification and desalination. Ways to purify water that reduce the use of chemicals, which negatively affect the environment, are desired (*3*).

Resource-limited environments would also benefit from methods to assess water quality that are portable, sensitive, and easy to implement. However, the allowable concentration of many contaminates in water suitable for human consumption often falls below the detection limit of existing assays, increasing the risk of false-negative reports (*4*). For example, in Chile, two sources of arsenic, antimony, and tellurium are hydrothermal and discharge streams from geysers, as well as the water used in copper production and purification—processes that introduce these toxic elements at unsafe levels for downstream farming and urban users. Chileans test drinking water using a variety of analytical methods that have been approved by the U.S. Environmental Protection Agency. The choice of analytical method depends on the water source and the suspected concentration range of the toxic element(s). Because concentrations are often higher near the Andes mountains and areas farther from cities, the cost, speed, and feasibility of analysis are major hurdles. Typically, results are not available for 1 week to 1 month after testing. In eastern Africa, similar obstacles prevent testing for high fluoride concentrations, because contaminated waters run through under-resourced villages with very little capacity to detect fluoride and other contaminants.

Recent efforts in water purification include coagulation-flocculation, oxidation, adsorption, ion exchange, and membrane processes to remove arsenic. A biologically inspired system for heavy-metal remediation centers is the use of spider silk, which is created by the self-assembly of water-soluble protein components. A nanotechnology-based water purifier created using ash from rice production has shown promise in filtering out microorganisms (www.sa-lives.com/images/lives_final_opt.pdf).

Microfluidics and paper-based devices offer low-cost, robust, portable, and easy to use technology for detection and monitoring of (bio)toxic substances in water (*5*). A standard cell phone with an LED bulb as the light source has been used to visualize *Mycobacterium tuberculosis* tagged with fluorescent makers, with the images sent to experts for analysis (*6*). Such cell phone–based approaches could be used to monitor bacteria in both drinking water and food in the field. Emerging technologies for the electrochemical detection of arsenic in water samples are very promising but are limited in moving from the lab to the field. Lab-on-a-chip technologies could facilitate the translation of electrochemistry to low-resource settings. Another major limitation of detection technologies is sample preparation and handling, which constitute more than 80% of the cost.

Regardless of the technology, goals must be defined based on the realities in each country in terms of scientific and manufacturing capabilities and willingness to solve a problem in a reasonable amount of time with limited resources. Biomedical engineers can bring their skills to develop approaches with increased sensitivity and lower cost. One area with powerful advances is in customizing cell phones, which are becoming extremely common in developing countries. These portable platforms could be used by rural community members to detect, document, report, and map hot spots of waterborne pathogens and contaminants.

SUFFICIENT AND SECURE FOOD

A growing global challenge is access to sufficient food that is safe and nutritious. Monitoring food safety becomes increasingly important as distances increase in the transportation of food from production to consumption sites: Up to 20% of food produced, including fruits and vegetables, is lost to spoilage worldwide (*7*). This is important in areas such as Asia that are using more food production and transportation resources. New diagnostic tools for detecting spoilage are needed for low-resource settings. Ideally, such devices would be inexpensive, and external power would not be needed to operate them.

Another problem of global importance is the lack of nutritious food in low- and middle-income countries. Engineering approaches, such as genetic modification and agroecology, can be used to increase the level of bioavailable nutrition in food products. Any approach to altering food, however, must be sensitive to concerns about genetically modified organisms, crop diversity, and molecular changes in the modified foods. There is ongoing debate about genetically modified crops, including questions about effects on the environment and pesticide resistance and the degree of control over world food supplies wielded by companies that produce the seeds.

As an alternative, "reverse engineering" can be used to understand self-assembly processes in nature and then apply this knowledge to produce foods with enhanced oxidative stability, shelf life, digestibility, and sensory acceptance, even as sugar and fat content is reduced. This may be a particularly important effort in curbing obesity, an emerging noncommunicable disease that threatens global health and raises health care costs. Aside from the food itself, engineering the packaging of food so it is edible as well has been explored by Quantum Designs [http://quantumdesigns.com]. These foods, called "WikiFoods," combine particles of chocolate, fruits, and grains with polymers, such as alginate, to create a skin-like packaging that protects the food inside and can be washed and eaten as part of the food item.

ENERGY SOLUTIONS

Biological approaches to generating energy could both reduce our carbon footprint and contribute to improved global health through the reduction of pollution generated from oil and coal consumption. Tremendous potential exists for the extraction or generation of energy using a wide range of organisms, including plants and plant waste (such as corn, lignin, and sugarcane), microorganisms (such as *Geobacter sulfurreducens* and *Shewanella oneidensis*) (*8*), and algae. For example, lipids (oils) can be chemically or mechanically extracted for use as biofuel from microalgae of numerous different species, including *Scenedesmus*, *Chlorella*, and *Botryococcus braunii* (*9*).

Engineers fluent in synthetic biology are working toward developing these biofuels, which currently operate only on a small scale. These alternate energy platforms must first be studied to understand whether there are knowledge gaps related to the byproducts generated from biological materials. It is also unclear whether these approaches are suitable for settings where water is a limited resource. We must also work on scaling up methods for environmentally sustainable and cost-effective mass production and implementation. Integrating biological systems such as algae with engineered systems that capture and use the energy will require skills at the interface of engineering and biotechnology. Efforts are under way to scale up algae production on many continents, including Algae.Tec in Australia, Oil Fox in South America, and Sapphire in North America. Although advances have been made, the costs of scaling up these systems to be competitive with current fuel prices remain challenging.

GLOBAL SOLUTIONS REQUIRE GLOBAL STAKEHOLDERS

In the early 1960s, efforts to increase agricultural production in developing nations focused on the type of crops and the use of chemical fertilizers and irrigation. This Green Revolution made India, and later, other nations such as China, self-sufficient, not only with regard to food grains but also cash crops, such as cotton (*9*). In India, one emphasis was on reducing the number of rice species from those that were convenient (n = ~30,000) to those that were most productive (n = ~10). Replacing species that were prone to disease and pests with those that produced a higher yield dramatically increased the amount of food production worldwide. Unfortunately, it also may have contributed to overpopulation and a loss of biodiversity, among other problems (*10*).

The shortcomings of the Green Revolution point to the importance of discussions among many stakeholders, including engineers; funders; utility companies; representatives from agricultural, energy, and manufacturing sectors; community, national, and international leaders; and policy-makers, to identify the most important underlying problems and to develop innovative yet feasible and sustainable approaches to solving them. Without first aligning incentives and goals, we will be hard pressed to implement any solutions that might be successfully developed. Furthermore, funding should be directed toward technologies that address market- and need-driven questions within these global challenges. Targeted funding will require technoeconomic analysis of the competing technologies that might be deployed. These solutions must also take into account nontraditional constraints imposed by those resource-limited communities. New models of financing the development and deployment of relevant technologies will be required. Local acceptance of new technologies will require closer interaction between engineering and social science disciplines.

Another important consideration is the rapid emergence in developing countries of a middle class at a rate faster than can be supported by available infrastructure, and at a rate faster than policies and infrastructure can be designed. The bioengineer interested in global health may need to incorporate these factors into their research and design educations to effectively improve lives in developing countries.

ACCELERATING GLOBAL HEALTH RESEARCH

To seriously address global health, more funding is needed. At the U.S. federal level, a "nonprofit" version of the small business innovation research (SBIR) funding system could be used to support biomedical engineers and other scientists seeking to develop technology that targets the needs of developing countries, with, initially at least, a greater emphasis on societal good than commercialization potential.

Another option would be to establish and maintain a curated repository of proposals and new ideas by engineers and other scientists that target priorities in food and water safety and clean energy. Such an open-access repository could be searched by investors, philanthropists, foundations, and other potential sponsors looking to support biomedical engineering projects that will improve global health via one of these other sectors. As an example, a repository for connecting like-minded people—researchers, funders, industry, and the public—has been proposed by a nonprofit organization in biomedicine, for speeding up the delivery of new treatments to patients (www.cureswithinreach.org/research/cureaccelerator). Having a centralized repository in which to deposit proposals with potential global impact is likely to help biomedical engineers and other scientists looking for the means to secure support for ideas that may not be major areas of current funding for more traditional biology- and disease-focused sponsors, such as the U.S. National Institutes of Health and National Science Foundation.

To encourage the adoption and maintenance of such a novel project-funding framework, we suggest organizing workshops without boundaries, such as an international meeting with concurrent real-time online participation, to generate brainstorming and collaborative project development. Participants would include engineers (biomedical, chemical, civil, and environmental), basic scientists (biologists, chemists, immunologists, parasitologists, and infectous disease experts), social leaders and advocates, industry, policy-makers, and nongovernmental organizations. Proposals could additionally be framed with an educational component to help undergraduate and graduate students recognize the value of research aimed at addressing global challenges, while giving them the opportunity to collaborate as a member of a diverse and motivated team. Providing the infrastructure through which scientists can see their science both generate new knowledge and make the world a better place would be a win-win for all stakeholders involved.

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