A hot cot in use at Queen Elizabeth Central Hospital, Malawi.

Deb Niemeier/UC Davis

VIEWPOINT

Optics and Photonics for the **Developing World**

Rebecca Richards-Kortum and **Jennifer Carns** discuss how new light technologies could improve health care in low-resource settings.

Advances in photonic technologies have led to significant improvements in health care; immunofluorescence microscopy, optical coherence tomography and fluorescence-activated cell sorting are all a routine part of medicine in high-resource settings such as the United States. With the low cost and low power consumption of many photonic technologies, it seems that they could also improve health care in low-resource settings, such as sub-Saharan Africa. However, a comparison of the per capita health care expenditures in the United States (over US$8,000) and Malawi (US$74) as reported by the World Health Organization gives an indication of the vast difference in resources available for health care between the two countries.

A visit to the neonatal unit at Malawi's largest teaching hospital, Queen Elizabeth Central Hospital, confirms the enormity of the health care technology gap between such settings. The hallway to the neonatal unit is lined with broken Western-style incubators, many donated by well-meaning aid organizations. Within the neonatal unit, babies are instead kept warm using a local innovation known as the Blantyre hot cot—a wooden crib that uses four incandescent light bulbs to warm the air in the crib.

The hot cot is a beautiful example of 18th century optics at work, saving lives in Malawi. Why is it so difficult to translate more recent advances in photonics to complement and extend the lifesaving capability of the Blantyre hot cot?

Implementation challenges

In many low-resource settings, the infrastructure needed to support modern health care technologies does not exist. These areas are often characterized by frequent power outages and line voltage fluctuations, uncontrolled temperature and humidity, a lack of trained technicians to operate and service equipment, and limited access to spare parts and consumable supplies. These challenges can quickly render donated equipment virtually useless. Furthermore, patients in the developing world often travel long distances to receive medical care, making it difficult to reestablish contact with the patient to discuss test results and treatment plans. Diagnostics must then be provided at the point of care if they are to lead to timely, effective treatments. These challenges are unique to low-resource settings and require technologies designed explicitly to address their needs.

Fortunately, many optical components, such as light-emitting diodes (LEDs) and image sensors, have become increasingly affordable and efficient, making them attractive candidates for low-cost battery-powered devices tailored to address the challenges of low-resource settings. Advances in solar-powered technology may further address the needs of remote areas where power outages are common. Furthermore, the increasing prevalence of mobile-phone technology, which can reach parts of the developing world that lack the infrastructure for other methods of reliable communication, may be leveraged to provide access to trained medical personnel in areas where this expertise is rarely available. A few specific examples are discussed below.

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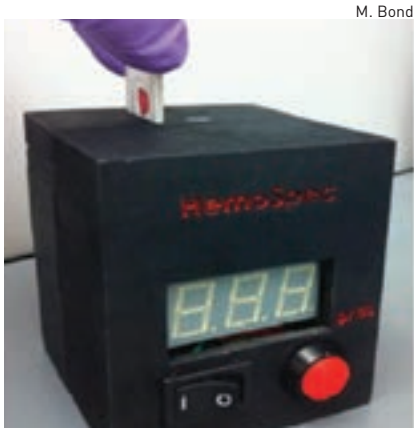
J. Viau Colindres

M. Bond



(Top) LED-based phototherapy system for treating jaundice and (bottom) Hemospec spectrometer to calculate hemoglobin concentration.

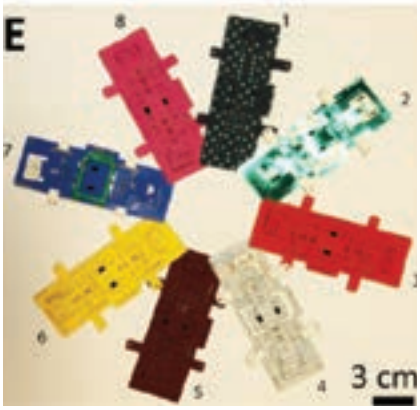
LED phototherapy for jaundice

Jaundice, caused by an excess of bilirubin in the blood, affects nearly 60 percent of newborns worldwide, according to the U.S. Centers for Disease Control and Prevention. In the developed world, jaundice is easily treated using phototherapy, or exposure to blue light, to photodecompose the bilirubin. However, when left untreated, jaundice can cause serious brain damage and can even be fatal. The cost of conventional phototherapy that uses halogen or fluorescent lights is too high for many low-resource settings, and donated lights still require replacement bulbs at a cost of several hundred dollars each. Recent studies have shown that blue-LED-based phototherapy systems can be as effective as conventional phototherapy, for a fraction of the cost (less than US$100 per system).

Low-cost hemoglobin concentration diagnostic

One of the most common blood tests performed in a primary care setting is a hemoglobin concentration assessment to diagnose anemia. Typically, a health care provider uses a reagent to convert hemoglobin to cyanmethemoglobin, a stable compound that can be analyzed with a spectrometer to yield hemoglobin concentration. A low-cost alternative, known as the HemoCue, uses plastic cuvettes and a portable analyzer to measure hemoglobin concentration. However, at roughly US$1 per disposable cuvette, this method is still too expensive for many low-resource settings. This problem is being addressed through the development of another system, the Hemospec, which uses cuvettes made of chromatography paper and an LED-based handheld reader to provide similar results at less than US$0.01 per test.

J.S. Cybulski



O. Neumann

(Left) origami-based Foldscope microscopes and (right) solar-powered autoclave using light-absorbing nanoparticles to produce steam.

Mobile-phone microscopy

The light microscope has perhaps been the most commonly used device in medicine since it first appeared over 400 years ago. While the developed world has experienced advances in microscopic techniques that have enhanced contrast and resolution, the developing world still struggles not only with the costs associated with maintaining basic microscopes, but even more importantly with access to trained microscopists to provide accurate diagnoses.

One possible solution is the microscope-enabled mobile phone, which could relay images to experts and provide real-time diagnostics to remote areas. The Foldscope, a microscope constructed from folded paper, a ball lens and a battery-powered LED, addresses both of these concerns. This robust platform demonstrates submicron resolution at a cost of less than US$1, and can be modified to incorporate fluorescence, dark-field and array modalities for evaluating multiple fields of view simultaneously. Furthermore, it can be coupled with a camera or mobile phone for the transmission of images, potentially providing affordable microscopy and access to experts for low-resource settings.

Ideally, these designs would be battery- or solar-powered to reduce the need for reliable power supplies.

Solar autoclave

Sterilization of medical equipment is vital to preventing infection in health care settings. Autoclaves, electrically powered devices which cost thousands of dollars, are often used to sterilize instruments with steam. In settings that lack a reliable supply of electricity, it can be difficult to ensure that medical devices are properly sterilized.

Light-absorbing nanoparticles have recently been shown to generate hot steam using sunlight collected by a low-cost Fresnel lens. This closed-loop solar autoclave can produce steam at a temperature of 115 °C for over 20 minutes, which meets U.S. Food and Drug Administration standards for the sterilization of medical and dental tools. Furthermore, the nanoparticles do not degrade as the steam is generated and thus can be used indefinitely.

Toward a sustainable system

To be sustainable, medical devices for the developing world must have minimal recurring costs and low-cost replacement parts that can be easily maintained. Ideally, these designs would be battery- or solar-powered to reduce the need for reliable power supplies. Future diagnostics based on *in vivo* microscopy or spectroscopy could completely eliminate the costs associated with consumables and greatly reduce the need for expensive tests, such as histopathology.

A commitment to both innovation and translation in the earliest stages of technology development can produce life-saving results. To paraphrase George Whitesides, technology needs to solve real problems in simple and cheap ways that are virtually invisible to the user. OPN

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To learn more ...

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