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Tools To Reduce Newborn Deaths In Africa

An engineering team designs a breathing device specifically for premature babies born in low-resource health care settings.

BY REBECCA R. RICHARDS-KORTUM

Our team left the dark hallway of the hospital in Tanzania—crowded with the rush of nurses and mothers—and entered the neonatal intensive care unit. There, in a small, quiet room the size of my fifth-grade daughter's bedroom, morning sun poured in through the window, reflecting off yellow walls and onto thirty-two plastic bassinets each holding a tiny newborn. In the bassinet nearest the door, a baby struggled to breathe. He shuddered with each slow breath, his skin a dusky gray. Our hosts, local physicians, leaped to intervene, pushing past us as they weaved their way through the small spaces between the bassinets. Their urgency pierced the calm; we stood back to give them room. We watched and waited. There was nothing they could do. The baby died. The room grew quiet again, and we resumed our tour of the rest of the hospital.

As a bioengineer working for twelve years with partners in Malawi to develop technologies to improve newborn and maternal health, I had seen many under-resourced hospitals like this one. But following this visit, I could think only of the tiny baby in the bassinet near the door. I imagined how his mother would learn the news. I imagined how difficult it would be for her to leave the hospital alone, to return home without him, never to see her baby's first smile but instead to plan his funeral. His big sister would never get to hold her baby brother. I grieved, knowing that this sad scenario would be repeated time and again, all across sub-Saharan Africa, where UNICEF reports that more than a million babies die every year.

I was traveling with a group of six women that included two engineers: my colleague Maria Oden, from Rice University, and Theresa Mkandawire, the University of Malawi's dean of engineering. We were joined by Joy Lawn, a neonatologist who is helping lead global efforts to set and monitor progress toward the global newborn health targets; Queen Dube, a pediatrician and cochair of the Department of Pediatrics at the University of Malawi College of Medicine; Kara Palamountain of Northwestern University's Kellogg School of Management, an expert in the development and adoption of medical technologies in Africa; and Bri Knoll, a Northwestern University medical student. Our team was meeting with local collaborators to craft a large grant proposal to strengthen newborn care at central and district hospitals in sub-Saharan Africa.

After witnessing the baby's death, we went on to see three more rooms, each with too many tiny babies and not enough medical equipment to provide life-saving newborn care—care that has been available for more than fifty years in the United States. As we left the last ward, a woman rushed past with a handful of papers. I later learned they were death certificates.

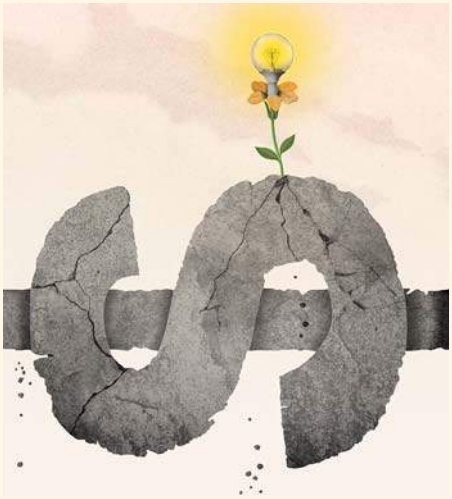
Newborn Survival

Babies born in poor settings die from a lack of simple tools—tools to keep them

Illustration by Brett Ryder

warm, monitor their vital signs, detect and treat jaundice, and help them breathe when they are born too soon. Efforts to improve community-based care have not translated into improvements in newborn survival. For example, a large randomized study in Tanzania of a home visit package involving community health workers found that the intervention did not significantly reduce mortality. The researchers reported in *PLOS Medicine* in 2015 that "action to improve neonatal survival in this setting should include a focus on improving the quality of facility-based childbirth care." Historical evidence shows that providing comprehensive hospital care during labor, delivery, and the first week of life can reduce newborn deaths by 75 percent, according to a 2013 article in *Reproductive Health*. Although most African mothers now give birth in hospitals, these facilities lack the technologies needed to provide comprehensive care for newborns, as Zulfiqar Bhutta, an expert on maternal and child health, and colleagues point out in a 2014 *Lancet* article. Frustrated pediatricians face shortages of vital equipment and supplies all across Africa, the region of the world where rates of newborn death are highest and where progress to improve newborn survival is slowest.

Well-meaning donors have tried to solve this problem by shipping surplus equipment from the United States to hospitals in Africa. Instead of helping improve care in the newborn ward, three-fourths of donated equipment fails, we've found, often shortly after arrival. Designed to work in America's pristine, air-conditioned hospitals, this equipment fails because it cannot withstand the harsh environmental conditions common in African hospitals and it succumbs to power surges, dust, heat, or humidity. The problem is made worse because equipment is often donated without a plan to provide a continuing supply of necessary consumables or spare parts needed for routine maintenance and repairs. Indeed, stockpiles of broken, unused equipment can be found in almost every African hospital, usually in a basement room known as the "equipment graveyard."



The Equipment Graveyard

During a visit to Malawi in 2014, my colleagues from Rice University and I found an equipment graveyard at Queen Elizabeth Central Hospital overflowing with eighty-three broken oxygen concentrators. The newborn unit needed twenty concentrators but had only four that worked. That year, our team began distributing the model of oxygen concentrator recommended by the World Health Organization to the newborn unit of every government hospital in Malawi. But despite routine preventive maintenance, two-thirds of these concentrators failed in under two years. This problem is not unique to Africa, either. In India, Special Care Newborn Units that contained radiant warmers, phototherapy lights, oxygen concentrators, pulse oximeters, and IV infusion pumps were established at district hospitals. Subsequently, neonatal fatality rates declined in 75 percent of facilities, according to a 2011 study published in the *Journal of Health, Population, and Nutrition*. But the researchers found that when equipment broke, repairs often took up to six months.

New approaches are needed to design equipment that will enable and sustain the delivery of high-quality care in resource-poor settings. Physicians and nurses need equipment that is effective, affordable, and rugged enough to last at least five years, and that can be locally maintained and repaired. Engineers need to begin their design efforts by understanding the context in which the equipment will be used.

Inside The Design Kitchen

Back home in Texas, Maria and I regrouped at Rice's Engineering Design Kitchen. Formerly a kitchen serving the north campus residential colleges, the facility now houses 18,000 square feet of rapid prototyping equipment that allows Rice undergraduates to engineer solutions to challenges posed by clients all around the world. Busiest late at night, the twenty-four-hour facility is full of all of the ingredients needed to cook up new technologies, and thus the "kitchen" moniker stuck. Maria and I work with pediatricians and nurses in Malawi and other countries in the region to identify challenges that can be solved by teams of engineering students working in the design kitchen.

It was here where eight years ago our team began developing a tool to help preterm newborns breathe. Preterm birth is the leading cause of newborn death globally, and more than 50 percent of babies born too soon struggle to breathe because their lungs are immature. In high-resource settings, this is easily treated using a tool called a Continuous Positive Airway Pressure (CPAP) device, but these devices cost more than $8,000 and require infrastructure (such as wall outlets that supply piped-in oxygen and pressurized air) that is not available in many African hospitals.

In the fall of 2009, Maria challenged a team of senior bioengineering students to design a low-cost CPAP system that could be used without a source of wall oxygen and air. They came up with the idea of using pumps similar to those in fish aquariums. They calculated the necessary flow and pressure and determined that they could match the performance of commercially available CPAP machines by using two aquarium pumps in the device.

The students' first prototype was built inside a plastic shoe box from Target, but the students showed that their CPAP device delivered the same flow and pressure as CPAPs used in high-resource settings. We demonstrated this prototype to pediatric nurses in Malawi, improving the design to make it more rugged and easier to use. We worked with 3rd Stone Design—a product development company in San Rafael, California—to adapt the design for commercial manufacture,

Policy Checklist

The issue: Comprehensive hospital care during labor, delivery, and the first week of life can reduce newborn deaths, but many newborn solutions and technologies are not well designed to provide care in low-resource health care settings. More low-cost, rugged technologies explicitly designed to function in Africa's challenging environments are needed.

Related Reading:

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and we took it through the international regulatory approval process. The resulting product costs one-tenth the amount of CPAP devices used in high-resource settings.

In Malawi, we showed that the system improved survival rates for preterm babies with respiratory distress syndrome from 24 percent to 65 percent, according to results reported in *PLOS ONE* in 2014, mirroring the improvement seen when CPAP devices were introduced in the United States. The system was named Pumani (a Chichewe word meaning "breathe restfully") by the pediatric nurses who helped scale up use of the technology to every government hospital in Malawi.

Together with colleagues at Queen Elizabeth Central Hospital and the Ministry of Health, we strengthened CPAP training for nurses and physicians and worked with the Ministry of Health and the Pediatric and Child Health Association of Malawi to incorporate CPAP in the national newborn care guidelines. Pumani was designed to tolerate the voltage spikes, dust, and heat that are found in Malawian hospitals, and each unit contains spare parts to facilitate repair and maintenance. During the same time that we saw 63 percent of brand-new oxygen concentrators fail, none of the Pumani CPAPs was sent to the equipment graveyard. Pumani is now saving newborn lives in thirty countries.

But CPAP addresses only one small part of newborn care. To improve survival rates in low-resource settings, nurses and physicians need access to all of the equipment required to deliver high-quality, comprehensive newborn care. Indeed, a number of other organizations are now working to develop neonatal technologies explicitly designed to function in low-resource settings. D-Rev, a nonprofit product development company in San Francisco, California, developed Brilliance phototherapy lights to treat babies with jaundice. The low-cost lights use long-lasting LEDs instead of expensive fluorescent bulbs and can withstand a wide range of power fluctuations. Bempu Health—a public health organization based in Bangalore, India—has developed a simple bracelet for babies that warns caregivers when an infant is too cold.

Together with local pediatricians, our team has reviewed the pathways of care to prevent or treat the leading causes of newborn death in Africa. We mapped the technologies needed to provide this care, making sure the list was complete. The result was a set of Newborn Essential Solutions and Technologies, or NEST for short. The NEST products include devices to provide breathing support (such as more rugged oxygen concentrators), prevent and treat infections, support hydration and nutrition (such as syringe pumps), monitor and treat jaundice, stabilize temperature (such as warming cribs), and diagnose common neonatal conditions (such as hypoglycemia) at the point of care. All of these tools should be present in a neonatal ward that separates newborns from older pediatric patients, with back-up power and ready access to spare parts and tools for maintenance.

Access to the items on the NEST list is essential if we are to achieve the global targets that have been set for newborn survival as part of the United Nations' Sustainable Development Goals, which aim for all countries to reduce neonatal mortality rates below 12 per 1,000 live births by 2030. In 2014 all UN member states also endorsed the Every Newborn Action Plan, with a goal of ending preventable newborn deaths by 2035. Most of today's commercially available newborn solutions and technologies have been designed for high-resource settings, and they would likely find their way quickly to the equipment graveyard. We need more products designed specifically to meet the needs of low-resource environments.

To create an ecosystem to sustain these technologies and stem the flow of equipment to the graveyard, we also must train biomedical technicians to maintain and service these technologies. Finally, we must strengthen biomedical engineering programs to engage young African inventors in the design of new technologies to address health challenges in their own countries. My colleague Theresa Mkandawire sees enormous opportunities for the young men and women of Africa in this. Just across the street from Queen Elizabeth Central Hospital, the Polytechnic, a college of the University of Malawi, has launched a new degree pro-

gram in biomedical engineering. Last year the Polytechnic built its own design kitchen with funding from the Lemelson Foundation. Supported by student and faculty exchanges, teams of Rice and Polytechnic students designed low-cost phototherapy lights to treat newborn jaundice that are now manufactured in Malawi and used in district hospitals throughout the country. In parallel, we developed a handheld device to diagnose jaundice in minutes right at the bedside. We estimate that this battery-powered device can be manufactured for less than $200 and that the consumable strips needed to run the test can be made for pennies in Malawi. And in the summer of 2017, students dissected failed oxygen concentrators, identifying common modes of failure. They designed ways to bring these concentrators back into service, using local tools and repairing the concentrators much more cheaply than could be accomplished with imported spare parts. Most importantly, they uncovered a serious but simple design flaw that, when addressed, should extend the life of new concentrators.

Francis Masi is one bright example of this next generation. Several years ago I visited a Malawian orphanage with Francis, then a Malawian engineering student and now a member of our team. He encouraged the young orphans to pursue careers in science, saying: "You have to remember that everything in science starts out as something small. We all must continue creating and inventing; we must pursue ideas that have the potential to make the world better, even if we have limited resources and even if the ideas seem impossible."

We cannot continue to stand by as a million babies die every year.

In many ways, the global situation for newborn health today parallels that of HIV/AIDS twenty years ago.

In the 1990s AIDS was thought to be an unsolvable problem in Africa: Treatments were too expensive, African health systems were too weak to deliver them, and some US policy makers believed that Africans couldn't manage to take medicines consistently. The first step toward scaling up AIDS treatment was to demonstrate that a solution was possible.

With the newborn health crisis, the global public health community has taken that first step: nonprofits, universities, and companies have developed technologies explicitly designed to function in Africa's challenging environments. Based on the cost of these alternatives, we estimate that newborn units in district hospitals across Africa could be supplied with the equipment they need for comprehensive newborn care for just $1.48 per birth—less than the 2016 UNICEF tender prices for a dose of pentavalent pneumococcal vaccine. And although they are designed for use at the district hospital level, many NEST tools could be easily adapted for use in primary health centers.

We cannot continue to stand by as a million babies die every year. It is time to move beyond the first step and work with local clinicians and engineers to deliver these technologies, and the complementary educational and training programs, throughout Africa. ■

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