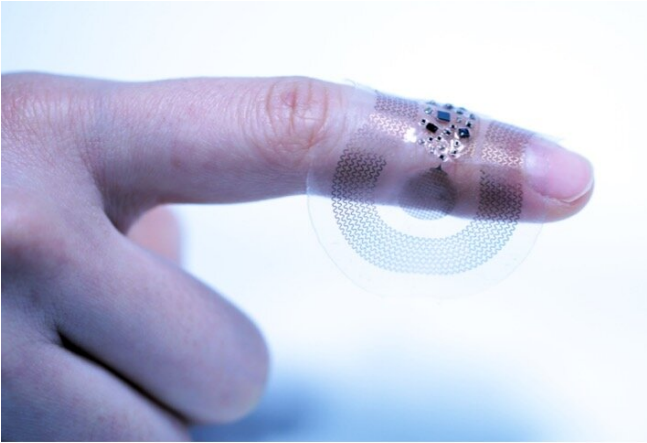


No wires, more cuddles: Sensors are first to monitor babies in the NICU without wires

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Weighing as much as a raindrop, the chest sensor can wirelessly monitor heart rate, breathing rate, and temperature. Credit: John A. Rogers/Northwestern University

An interdisciplinary Northwestern University team has developed a pair of soft, flexible wireless sensors that replace the tangle of wire-based sensors that currently monitor babies in hospitals' neonatal intensive care units (NICU) and pose a barrier to parent-baby cuddling and physical bonding.

The team recently completed a series of first [human studies](#) on [premature babies](#) at Prentice Women's Hospital and Ann & Robert H. Lurie Children's Hospital of Chicago. The researchers concluded that the wireless sensors provided data as precise and accurate as that from traditional monitoring systems. The wireless patches also are gentler on a newborn's fragile skin and allow for more skin-to-skin contact with the parent. Existing sensors must be attached with adhesives that can scar and blister premature newborns' skin.

The study, involving materials scientists, engineers, dermatologists and pediatricians will be published March 1 in the journal *Science*.

The study includes initial data from more than 20 babies who wore the wireless sensors alongside traditional monitoring systems, so Northwestern researchers could do a side-by-side, quantitative comparison. Since then, the team has conducted successful tests with more than 70 babies in the NICU.

"We wanted to eliminate the rat's nest of wires and aggressive adhesives associated with existing hardware systems and replace them with something safer, more patient-centric and more compatible with parent-child interaction," said John A. Rogers, a bio-electronics pioneer, who led the technology development. "We were able to reproduce all of the functionality that current wire-based sensors provide with clinical-grade precision. Our wireless, battery-free, skin-like devices give up nothing in terms of range of measurement, accuracy and precision—and they even provide advanced measurements that are clinically important but not commonly collected."

Rogers is the Louis Simpson and Kimberly Querrey Professor of Materials Science and Engineering and Biomedical Engineering in the McCormick School of Engineering and a professor of neurological surgery in the Feinberg School of Medicine. He co-led the research with Dr. Amy Paller, dermatology department chair, Walter J. Hamlin Professor of Dermatology and professor of pediatrics at Feinberg, and Dr. Shuai (Steve) Xu, an instructor of dermatology at Feinberg and a Northwestern Medicine dermatologist.

Cutting the cords

The mass of wires that surround newborns in the NICU are often bigger than the babies themselves. Typically, five or six wires connect electrodes on

each baby to monitors for breathing, blood pressure, blood oxygen, heartbeat and more. Although these wires ensure health and safety, they constrain the baby's movements and pose a major barrier to physical bonding during a critical period of development.

"We know that skin-to-skin contact is so important for newborns—especially those who are sick or premature," said Paller, a pediatric dermatologist at Lurie Children's. "It's been shown to decrease the risk of pulmonary complications, liver issues and infections. Yet, when you have wires everywhere and the baby is tethered to a bed, it's really hard to make skin-to-skin contact."

New mother frustrated by inability to hold her newborn

New mother Taschana Taylor is familiar with that frustration. After an emergency C-section, Taylor's daughter Grace was rushed to the NICU, where she remained for three weeks. Desperate to bond with their new baby, Taylor and her husband felt exhausted when navigating the wires to provide Grace with the most basic care. Grace is among the 70 babies who have participated in the side-by-side comparison study so far.

"Trying to feed her, change her, swaddle her, hold her and move around with her with the wires was difficult," Taylor said. "If she didn't have wires on her, we could go for a walk around the room together. It would have made the entire experience more enjoyable."



Weighing as much as a raindrop, the chest sensor can wirelessly monitor heart rate, breathing rate, and temperature. Credit: Northwestern University

Stressful and difficult to take baby out of crib

"The gyrations that parents and nurses have to go through just to take the baby out of the crib are astounding," said co-author Dr. Aaron Hamvas, the Raymond and Hazel Speck Berry Professor of Neonatology at Feinberg and division head of neonatology at Lurie Children's.

"Wires are going up to the monitor, down to the baby, maybe going through holes in an incubator," Hamvas said. "Nurses and parents try to get the babies all bundled, so they don't accidentally pull anything off them or out of the wall. It's very, very cumbersome and stressful. If the baby were totally unencumbered, it would be tremendously more efficient and less prone to problems."

"Anybody who has had the experience of entering a NICU immediately notices how tiny the babies are, and how many wires and electrodes are attached to them," said co-author Dr. Debra Weese-Mayer, the Beatrice Cummings Mayer Professor of Pediatric Autonomic Medicine at Feinberg and chief of Pediatric Autonomic Medicine at Lurie Children's. "The opportunity to go wireless has enormous potential for decreasing the burden for the nurses, for the babies and for the parents."

Going beyond current possibilities

The benefits of the Northwestern team's new technology reach beyond its lack of wires—measuring more than what's possible with today's clinical standards.

The dual wireless sensors monitor babies' vital signs—heart rate, respiration rate and body temperature—from opposite ends of the body. One sensor lays across the baby's chest or back, while the other sensor wraps around a foot. (The chest sensor measures 5 centimeters by 2.5 centimeters; the foot sensor is 2.5 centimeters by 2 centimeters. Each sensor weighs about the same as a raindrop.)

This strategy allows physicians to gather an infant's core temperature as well as body temperature from a peripheral region.

"Differences in temperature between the foot and the chest have great clinical importance in determining blood flow and cardiac function," Rogers said. "That's something that's not commonly done today."

Physicians also can measure blood pressure by continuously tracking when the pulse leaves the heart and arrives at the foot. Currently, there is not a good way to collect a reliable blood pressure measurement. A blood pressure cuff can bruise or damage an infant's fragile skin. The other option is to insert a catheter into an artery, which is tricky because of the slight diameter of a premature newborn's blood vessels. It also introduces a risk of infection, clotting and even death.

"We are missing a great deal of information where there may be variations in blood pressure over the course of the day," Hamvas said. "These variations in blood pressure may have a significant impact on outcomes."

The device also could help fill in information gaps that exist during skin-to-skin contact. If physicians can continue to measure infants' vital signs while being held by their parents, they might learn more about just how critical this contact might be.

Transparent and compatible with imaging, the sensors also can be worn during X-rays, MRIs and CT scans. "Wires are not just a physical impediment to interacting with the baby but also disrupt imaging if left in place," Paller said. "The technology has been developed so you can do imaging with the sensors in place and continue monitoring the baby."



Credit: Northwestern University

Saving 'incredibly fragile' skin

The [blood pressure](#) cuff isn't the only potentially damaging part of current technology. Many premature babies suffer skin injuries from the sticky tape that adheres the wires to the body. Tape can cause skin irritation, blisters and, ultimately, infections. In some cases, this damage can lead to lifelong scarring.

"Premature babies' skin is not fully developed, so it's incredibly fragile," Paller said. "In fact, the thickness of the skin in premature infants is about 40 percent reduced. The more premature you get, the more fragile the skin becomes. That means we have to be very careful."

The Northwestern team has studied 70 babies in the NICU thus far and found no sign of skin damage from the wireless sensors. The sensor's skin-saving secret lies in its lightweight nature, thin geometry and soft mechanics. The paper-thin device is made from bio-compatible, soft elastic silicone that embeds a collection of tiny electronic components connected with spring-like wires that move and flex with the body.

Rogers worked with longtime collaborator and stretchable electronics and theoretical mechanics expert Yonggang Huang to come up with an optimal design. Huang is a Walter P. Murphy Professor of Civil and Environmental Engineering

and Mechanical Engineering and professor of materials science and engineering at Northwestern's McCormick School.

"Improving care of critically ill newborns," *Science* (2019). [science.sciencemag.org/cgi/doi ... 1126/science.aaw2085](https://science.sciencemag.org/cgi/doi/10.1126/science.aaw2085)

"If you look back to the 1960s, the basic approach to monitoring infants is essentially the same as it is today," Rogers said. "It's taped-on sensors, wires to external boxes of electronics. That's all that's ever been done."

Provided by Northwestern University

"The strength of the adhesive required to keep our lightweight device on the skin is much lower than that of the kinds of adhesives needed to maintain an interface between a hardwired sensor and an external box," Rogers continued. "We have seen no adverse side effects in our study, not even a hint of skin injury even in the most frail babies."

The [wireless sensor](#) communicates through a transmitter placed underneath the crib's mattress. Using radio frequencies the same strength as those in RFID tags, the antenna transmits data to displays at the nurses' station. Although it can be sterilized and reused, the sensor is cheap enough (about \$10) that it can simply be discarded after 24 hours and replaced with a new one to eliminate any risk of infection.

When will wireless sensors appear in U.S. hospitals?

Rogers estimates that his wireless sensors will appear in American hospitals within the next two to three years. With support from two major nonprofit organizations, Rogers' team expects to send [sensors](#) to tens of thousands of families in developing countries over the next year as part of an international effort.

"We're proud of the fact that this technology isn't just limited to advanced NICUs in developed countries," Xu said. "The technology can be adapted with minimal modification for low-resource settings."

More information: H.U. Chung et al., "Dual wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care," *Science* (2019). [science.sciencemag.org/cgi/doi ... 1126/science.aau0780](https://science.sciencemag.org/cgi/doi/10.1126/science.aau0780)

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