HealthManagement.org
The Journal
LEADERSHIP • CROSS-COLLABORATION • WINNING PRACTICES
VOLUME 18 • ISSUE 3 • 2018 • € 22
ISSN = 1377-7629

Emerging Markets

Game-changing skin-like electronics for stroke patients

Enabling continual monitoring and personalised care

An innovative new wearable for the throat could mean a turning point for care of stroke patients.

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Developments in skin-close wearable electronics are presenting healthcare with a breadth of new devices that can enable continued monitoring outside the hospital or rehab clinic, presenting a significant step forward in personalised care. These pioneering devices were brought about through a marriage of sophisticated engineering and electronics, as John A. Rogers explains:

A variety of stretchable electronics have been produced by our team of engineers at Northwestern University, Chicago, enabling enough precision for use in advanced medical care and enough compactness and flexibility to be worn outside the hospital, even during vigorous activities. The devices present patients with ongoing monitoring that impacts minimally on their lifestyle. Meanwhile, healthcare professionals are able to collect data about individual patients that was previously untapped—a continual flow of data through patients' daily lives.

The intermodal system of sensors that are placed on patients stream data wirelessly to clinicians' phones and computers, providing a full-body picture of patients' advanced physical and physiological responses in real time.

Ground-breaking use in stroke patients

The latest device in the growing portfolio of stretchable electronics is a monitor that can be worn on the throat and which could be a game changer in the field of stroke rehabilitation. Along with this, sensors can be placed on various other parts of the body to monitor body functioning and recovery progress. In stroke patients, sensors on the arms, legs and chest track patients' movements with a level of precision traditional wearables cannot achieve.

A big problem with stroke patients is that their gains tend to drop off when they leave the hospital. This is where these sensors can offer incredible value—they can alert health carers of the right time to intervene, which could lead to better, faster recoveries for patients.

The sensors stick directly to the skin and move comfortably with the body while providing detailed health metrics, including heart function, muscle activity and quality of sleep. The new throat sensor measures stroke patients' swallowing ability and patterns of speech, aiding in the diagnosis and treatment of aphasia, a communication disorder associated with stroke.

Whilst the tools that speech-language pathologists traditionally use to monitor patients' speech – such as microphones – cannot distinguish between patients' voices and ambient noise, these sensors measure vibrations of the vocal cords, thus solving that problem. This is only possible when worn directly on the throat, however. Throughout development of our devices, minimising discomfort to patients was of high importance, and we created novel materials that bend and stretch with the body, even allowing comfortable use on sensitive areas such as the throat.

A malleable structure

The key to the development of these stretchables was to find ways to use hard, brittle materials, like devices built with silicon, in formats that are soft and conformal to surfaces of biological tissues. Our strategies use laser cut platforms that serve as open network mesh architectures of interconnected active devices, entirely encapsulated into soft silicone elastomers. This combination yields systems that can be very thin and skin-like in their properties, yet still embed some of the most advanced components in modern electronics.

The challenge we faced when developing these stretchable electronics was to combine advanced mechanics designs and geometrical architectures with topologies needed for circuit operation – it's a coupled exercise in circuit and mechanics design, where layout considerations integrate into both areas. Another

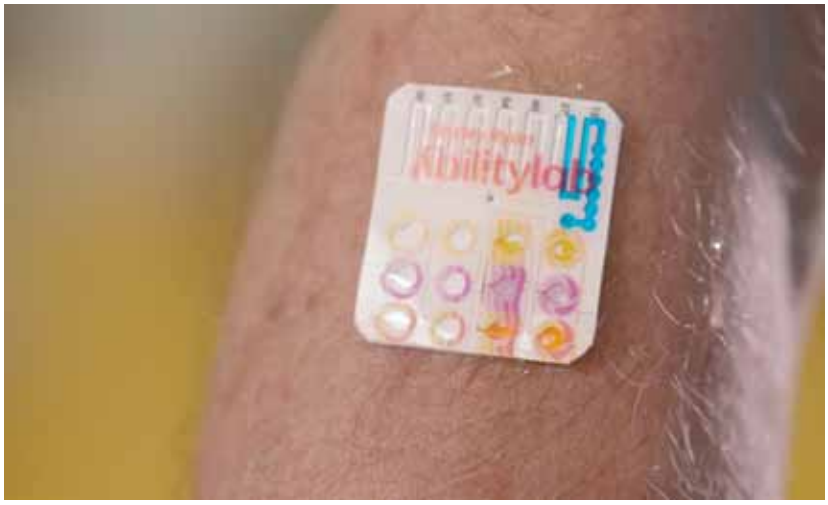
related aspect was in mechanical robustness against many cycles of bending, stretching, twisting, and so on. The solutions are in materials and mechanics designs that avoid excessive stresses on the active components and instead localise the deformations into the silicone material.

> “A BIG PROBLEM WITH STROKE PATIENTS IS THAT THEIR GAINS TEND TO DROP OFF WHEN THEY LEAVE THE HOSPITAL”

The stretchable electronics integrate with the skin using a double sided, thin fabric material adapted from the skin bandage industry. This adhesive is single-use, such that the devices themselves can be reused indefinitely. It means that the device can be taken on and off as required and as is convenient for the patient. A typical duration for wearing a device might range anywhere from five to 12, to several days. So far, in terms of the device’s comfort and use, we have received very positive feedback from physicians, nurses, rehabilitation experts and the patients themselves.

Wearing in the new technology

We started working on the idea of stretchable electronics about 12 years ago, culminating with a first



paper, "A Stretchable form of single crystal silicon for high performance electronics on rubber substrates" (Khang et al.), published in *Science* in 2006. Then, in the same journal, in 2011, we published our first paper on skin-like electronics in an article entitled "Epidermal electronics" (Kim et al.). Since then, we have developed a broad sensor suite, a set of power supply options and two different wireless communication schemes for complete systems that can address important challenges and opportunities in clinical medicine.

One aspect of the device has raised issues, and this is in terms of privacy, as is a common concern in today's technology-rich world. Data security is important in this context, as it is for many other applications—wireless payments, communications, and so on. As with other applications, the data can easily be encrypted in a way that addresses many of these concerns.

Stretchable electronics of the future

We are working to expand the range of sensing capabilities of these devices. For instance, we have new devices that combine microfluidic networks along with the electronics. In this way, we can capture, store and perform biomarker analysis on sweat—thereby yielding biochemical information that can complement the types of biophysical data that we can collect with our electronic sensors.

Over time, the devices will get smaller. In one example, we were able to build a blood oximeter that is small enough (about the diameter of a single M&M candy, and about as thick as a credit card) to mount on the fingernail. The nail serves as an optical window for reflection-mod measurements in the underlying tissue bed.

Because the sensors are wireless, they eliminate barriers posed by traditional health monitoring devices and are enabling doctors to get a far deeper understanding of how their patients are functioning in the real world. We look forward to seeing widespread use of our devices and are meanwhile continuing with our research and development at Northwestern University, to continue to add to the capabilities of our stretchable electronics. ■

KEY POINTS

- ✓ The stretchables provide stroke patients with ongoing and non-intrusive monitoring and healthcare personnel can gather a continual flow of data for better care
- ✓ The comfortable and malleable sensors measure vocal cords for a more accurate picture on patient condition
- ✓ An intermodal sensors system stream data wirelessly to clinicians' devices providing full, real-time patient data
- ✓ Patients can wear the device anywhere from five to 12 hours to several days
- ✓ Data is encrypted for patient privacy and protection

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