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Engineering

The electronic patch that's impervious to sweat

Yifan Rao & Nanshu Lu

A smart adhesive patch that wicks sweat away from electronics embedded in its centre offers comfortable and reliable sensing of the wearer's biometrics or environment without the risk of perspiration damaging the devices. **See p.84**

Human skin is a remarkable organ that can regulate body temperature by secreting sweat that then evaporates. Sweat-wicking fabrics can draw trapped moisture away from the skin, preventing irritation, but it is complicated to incorporate such materials into wearable electronic patches that contain sensors and circuits for biometric or environmental monitoring. These smart patches must be small and soft, but they also need to resist sweat, which can make the patch peel off and lead to signal loss. Sweat can also seep into the electronics, causing short circuits and corrosion. Although the softness of these patches continues to improve, as does their ability to conform to the wearer's skin[1,2], the challenges of perspiration persist. On page 84, Zhang *et al.*[3] report a flexible device that can discharge sweat rapidly and strategically, ensuring comfort and signal stability during prolonged wear.

Previous designs for wearable electronic patches involve mesh-like electrodes that don't have backing layers, making them very breathable[4,5]. However, the absence of a substrate supporting the electrodes makes it difficult to attach these devices to the skin and to integrate them with advanced electronics. Other designs have incorporated permeable substrates that discharge vapour and sweat through micrometre- or nanometre-sized pores[6–9], but such openings can allow sweat to flow both ways.

These problems can be solved by using fabrics whose wettability changes gradually across their thickness to support the mesh electrodes. Such fabrics facilitate unidirectional liquid transport, because the liquid is driven from the side with a lower surface energy (making it hydrophobic) to the side with a higher surface energy (hydrophilic), whereas flowing in the reverse direction requires too much energy[10]. This concept inspired Zhang *et al.* to engineer the first component of their patch – a device called a vertical liquid diode, which allows liquid to seep from the bottom to the top, but not the other way (Fig. 1).

The authors began their fabrication process by immersing a polyester fabric in a suspension that made it superhydrophobic, and then dip-coated one side of the fabric with a water-based adhesive. The superhydrophobicity of the fabric prevented its porous structure from being compromised by the adhesive. Zhang *et al.* then used a stencil to selectively treat some regions of the other side of the fabric with oxygen plasma (ionized gas), which resulted in these areas becoming hydrophilic.

In this way, the authors created a wettability gradient that spontaneously directed sweat produced at the skin–fabric interface to the top of the fabric in droplet form, effectively preventing any backflow. When optimized, the vertical liquid diode could transport sweat at a rate of 11.6 millilitres per square centimetre per minute, and it remained effective for more than one month. This transport rate is particularly impressive because it is at least 4,000 times faster than the rate at which human sweat is discharged during mild exercise.

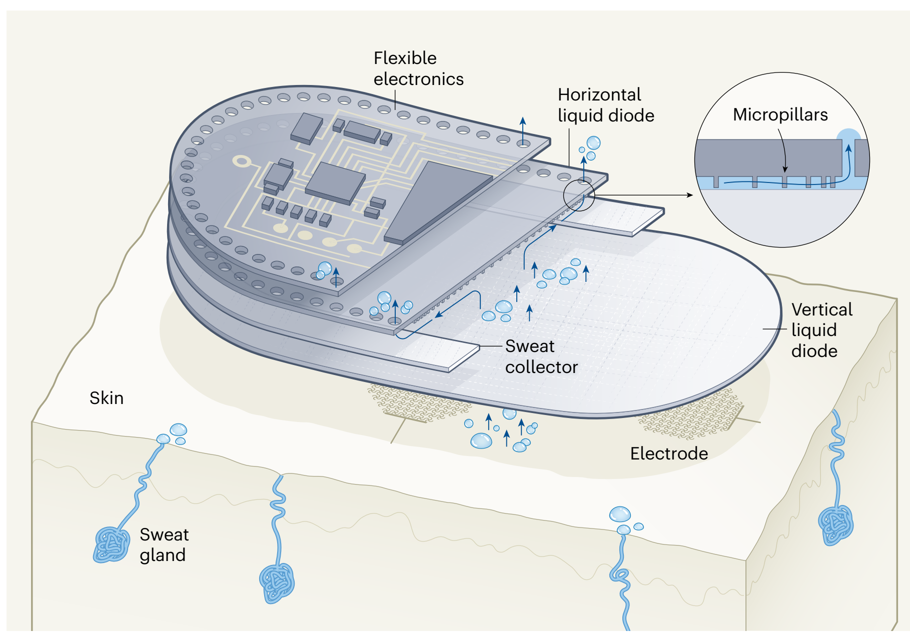

Figure 1 | Sweat-wicking wearable electronics. Zhang *et al.*[3] designed a wearable electronic patch by combining two liquid diodes – devices that allow liquid to flow in one direction only. The vertical liquid diode was made of fabric that was hydrophilic on the top and hydrophobic on the bottom, making sweat produced on the surface of the skin move through the fabric from the bottom to the top. A horizontal liquid diode on top of the vertical one used micropillars distributed in a non-uniform manner to drive the sweat that reached the top of the vertical liquid diode to the edges of the patch, where it was released from outlets. A ring of polyester fabric between the two layers acted as a sweat collector, and all three components were positioned between mesh-like electrodes and a layer of flexible electronics. This smart design is more comfortable than existing wearable electronics, and stabilizes signals produced by the device. (Adapted from Fig. 2a of ref. 3.)

The authors then went a step further to protect any electronics affixed to the surface of the fabric by ensuring that the sweat was not dispersed across this surface, but instead was repelled to the edges of the device. To do so, they designed a horizontal liquid diode and placed it on top of the vertical liquid diode. The horizontal diode comprised superhydrophilic micropillars that were all identical in shape, but were spatially distributed such that they were sparse near the centre and dense towards the edge. This configuration created a radial surface-energy gradient that guided sweat outwards, even under deformation and after prolonged exposure to sweat.

Zhang *et al.* joined the two liquid diodes together using a ring of polyester fabric that acted as both an adhesive and a sweat collector. This ensured that any electronics integrated into the centre of the substrate would remain unaffected by perspiration, which was pumped automatically to the sweat collector around the edge of the patch. The collected sweat either evaporated into the surrounding environment through the sweat collector or dripped from outlets at the top and edges of the device.

The team demonstrated the versatility of the patch by integrating it with various wearable electronic systems that were connected using detachable magnets. For example, when electrocardiogram (ECG) electronics were incorporated into the patch, it adhered to skin better and showed lower levels of signal interference than did existing ECG patches, providing stable heart-rate readings over the course of a week. The authors also showed that they could integrate an device for electromyography (EMG) – which measures electrical activity in muscles – into the patch.

Zhang *et al.* even demonstrated that their design could be incorporated into a T-shirt embedded with electronics that recorded real-time meteorological parameters, such as temperature – making the garment a wearable weather station. The T-shirt wicked sweat away from the sensors, allowing them to provide accurate readings as the wearer hiked up Hong Kong's Beacon Hill. This suggests that the authors' device will benefit both outdoor enthusiasts and people working in challenging environments. It could even be useful in heavily humid or rainy conditions in future. However, further research will be required to make the current design suitable for such conditions.

Reducing the thickness of the sweat-discharging patch (currently 650 μm) could enhance its wearability further and make it less noticeable to the wearer, especially when it is placed on areas of the body with large curvature or high deformability, such as the joints or the neck. These future improvements aside, Zhang and colleagues' clever integration of two custom-designed liquid diodes is compatible with a range of devices and fabrics, and therefore shows immense promise for developing high-performance wearable patches or smart textiles that contain complex electronic components.

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Memory

Neuronal inflammation makes memories persist

Benjamin A. Kelvington & Ted Abel

A population of neurons that engages mechanisms of the innate immune system during memory formation has been uncovered in mice. Surprisingly, inflammatory signalling might pave the way for long-term memory. **See p.145**

How do memories last? Spanish surrealist Salvador Dalí pondered this question in his famous work *The Persistence of Memory*. He also explored the tragic consequences of memory-loss conditions in *The Disintegration of the Persistence of Memory*. As the global population ages and diagnoses of Alzheimer's disease and related forms of dementia increase, the mechanisms that enable memories to last have captured the attention of neuroscientists. Yet what enables brief experiences, encoded over just seconds, to be replayed again and again during a lifetime remains a mystery. On page 145, Jovasevic and colleagues[1] fit a crucial piece into this puzzle by describing molecular mechanisms that are essential for memory and mark a new population of neurons.

In the 1950s, a man referred to as H.M. had part of his brain's temporal lobes surgically removed in an attempt to treat his epilepsy, but he was left incapable of forming new memories. Since then, scientists have homed in on the hippocampus – one of the areas removed from H.M.'s brain – as a hub for many types of memory[2].

Neuroscientists are now focused on determining how populations of neurons in the hippocampus respond to memory-inducing stimuli. Groundbreaking work has revealed that a population of neurons known as the engram is required for memory formation[3]. Engram neurons are characterized by the expression of a set of genes called immediate early genes, which is rapidly induced after learning. The current work uncovers a population of neurons that instead shows activation of innate immune signalling days after learning (Fig. 1).

Jovasevic and colleagues assessed gene expression in mice after contextual fear conditioning, in which mice learn to associate a small electric shock with a new environment. They compared mice 4 days after conditioning (a recent-memory timepoint) and 21 days after conditioning (a remote-memory timepoint) and found that the hippocampus of mice at the recent-memory timepoint showed signs of inflammation that were indicative of activated signalling by the protein Toll-like receptor 9 (TLR9). TLR9 triggers an innate immune response to DNA in the cell's cytosol that typically results from bacterial pathogens[4]. The authors showed that, in neurons, this inflammation is induced by persistent DNA damage and the release of TLR9-activating DNA fragments from the neuron's own nuclear genome.

Rapid induction of immediate early gene expression is known to require double-strand DNA breaks that are rapidly repaired[5]. However, Jovasevic *et al.* discovered that, in a population of neurons that is mostly distinct from a population expressing the immediate early gene *cFos* (a marker of the engram), DNA