sections of filter paper in a suspension of the probe and allowing them to air dry. These strips could then be immersed directly into a suspension of interest and photographed under UV-light illumination. This test was performed for a range of concentrations of tetracycline, and the resultant testing papers exhibited the expected blue to red color change (Figure 1C). The team next developed a smartphone application that could analyze these photographs in terms of their red and blue color content and demonstrated that the ratio of red to blue color (R/B) obtained in this way showed a linear relationship to the tetracycline content of the testing solution (Figure 1D) and good agreement with data obtained by HPLC.

In summary, Yue et al. report a novel fluorescent probe that can selectively detect tetracycline residues in both buffer solutions and food extracts with good agreement to results obtained by HPLC methods (one of the currently preferred methods of quantifying antibiotic residues in food products). The authors showed that the probe can be easily loaded onto filter paper to produce cost-effective and readily accessible testing strips to detect and quantify tetracycline residues using a smartphone application.

DECLARATION OF INTERESTS

The author declares no competing interests.

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Creating breathable wearable bioelectronics using three-dimensional liquid diodes

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A three-dimensional liquid diode has been developed to transport sweat and create breathable bioelectronics. The utilization of hydrophilic and curvature gradients facilitates water lifting, enhancing the adhesion time and signal stability of biosensors. Its waterproof nature enables the detection of trace-level biomarkers and integration with wearable monitoring systems.

The development of wearable point-of-care systems and precision medicine has seen a significant surge in recent years.[1,2] The conventional health care system faces challenges such as inadequate distribution and delayed appointments with doctors, leading to an increased mortality rate. The progression of chronic diseases like coronary heart disease and diabetes mellitus occurs before diagnosis, making it crucial to monitor these conditions. The failure to monitor such conditions with wearable bioelectronics, including electronic skins (e-skins), could lead to sudden death and significantly threaten local medical systems.

In response to the growing demand for long-term monitoring, recent developments have focused on creating e-skins that are thin and stretchable and can seamlessly integrate with the user's body while ensuring breathability.[1] Breathable bioelectronics, based on porous, nanofiber, and nanomesh architectures, can

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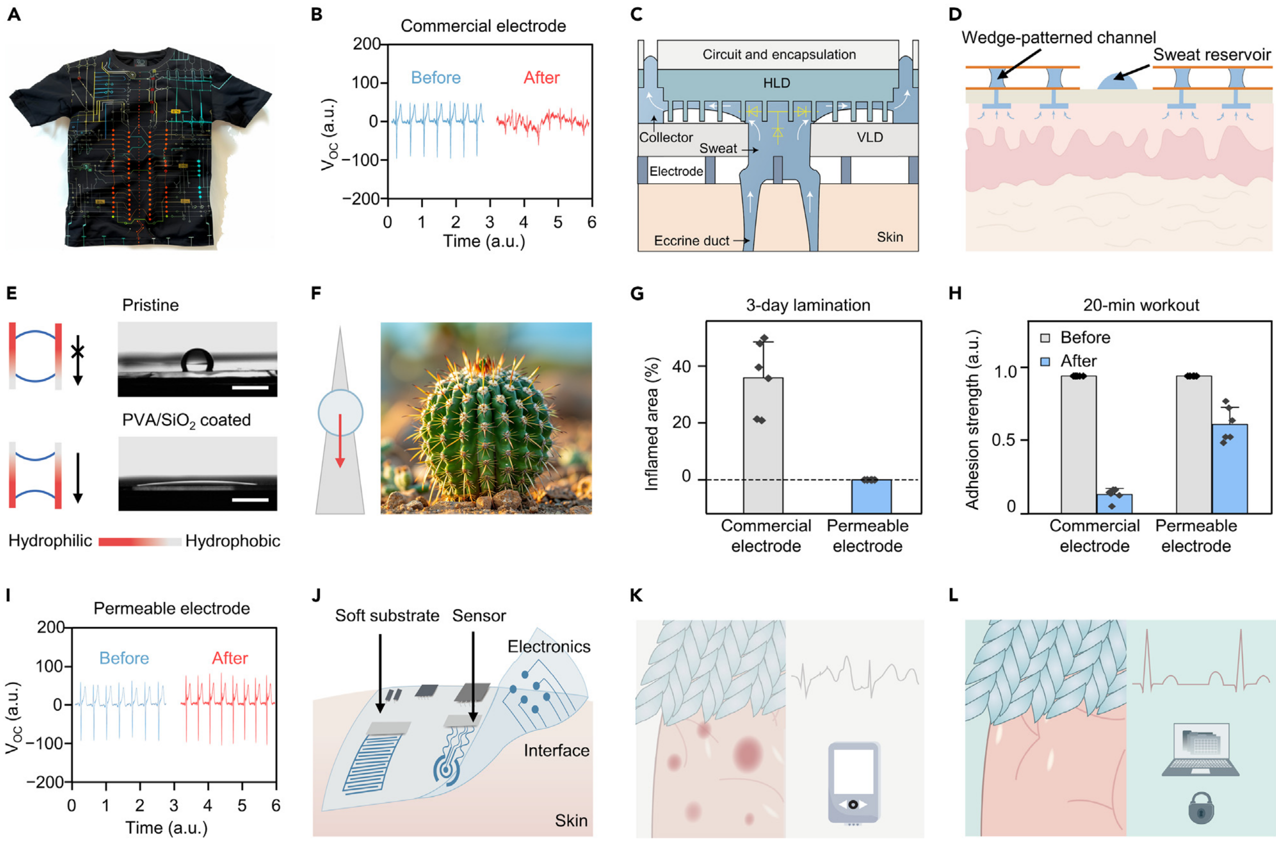

Figure 1. A breathable liquid diode for creating moisture-permeable wearable bioelectronics

(A) Schematic of point-of-care electronic skins designed for both comfort and breathability.
(B) Electrocardiogram signals recorded using commercial electrodes before and after exercise.
(C) Schematic of three-dimensional liquid diode that facilitates sweat transport from the bottom layer to the top.
(D) Schematic demonstrating the sweat collection process within a channel patterned in a wedge shape.
(E) Contact-angle measurements comparing two surfaces: one of pristine polydimethylsiloxane (PDMS) and the other featuring PDMS coated with PVA/SiO_2 nanoparticles. Scale bar: 750 μm.
(F) Photographs of a cactus spine holding a water droplet.
(G) Inflamed skin area after wearing electrodes for 3 days quantified as the mean $\pm$ standard deviation (SD).
(H) Adhesion strength of the electronic-skin interface following a 20-min workout.
(I) Electrocardiogram signals captured with permeable electrodes before and after exercise.
(J) Schematic of the electronic-skin interface.
(K) Traditional electronics have limited adhesion time and signal stability, which can lead to skin inflammation and disconnection with wireless technology.
(L) Permeable electronics enhance the comfort, adhesion strength, and signal stability of wearable devices. They also facilitate the integration of system-level electronics.
(B), (E), and (G)–(I) are adapted from Zhang et al.[3] with permission from *Nature*.

actively or passively transport gases and sweat from the skin's surface to the outer layer of e-skins, fostering a comfortable and robust interface between skin and electronics (Figure 1A).

However, e-skins designed to monitor biological signals rely on the triboelectric effect, piezoelectric effect, and piezoresistive effect to convert subtle biomechanical motions into analog signals.[2] These electronics are highly sensitive to water, which can alter the surface charges of materials and interfere with the electricity generated by the sensors, negatively impacting their performance. Although waterproof materials and hydrophobic silicone coatings can protect biosensors, they can lead to skin issues like edema or inflammation due to airtightness. Moreover, the adherence of commercial biosensors through electrostatic interaction is compromised by sweat, hindering the detection of physiological signals with satisfactory sensitivity (Figure 1B).

To address these challenges, a three-dimensional liquid diode design has been developed to efficiently extract sweat from the skin and distribute it to the hydrophilic layer of electronic devices. This system incorporates a vertical liquid diode (VLD) for sweat extraction and a horizontal liquid diode (HLD) for distribution (Figure 1C). The hydrophobic VLD at the bottom layer features a hydrophilic-treated roof to exploit surface tension differences, facilitating water droplet transport.[3] Despite the hydrophobic structure's low affinity for water, the hydrophilic treatment on the roof of the VLD enables it to attract water. When a water droplet contacts a narrow capillary with a hydrophilic surface, the contact angle is between 0° and 90°. This surface tension acts against gravity, lifting droplets above the liquid level. Conversely, contact with a hydrophobic surface results in a contact angle between 90° and 180°, displacing water within capillaries below the liquid level. In a pore, surface tensions from both the roof and bottom combine to form a composite force, driving the droplet toward the top of the channel (Figures 1D and 1E). Additionally, the VLD utilizes diameter-scale channels, inspired by cactus spines, to extract sweat from the skin.[4] The channels' lower curvature at the bottom facilitates droplet movement upward (Figure 1F), aided by the Laplace pressure toward the channel's roof.[5] This combination of hydrophilic gradient and wedge-shaped design drives efficient sweat extraction.

Several strategies exist to enhance the hydrophilicity of material surfaces. Dioxygen plasma treatment increases the hydroxyl group ratio, making the surface more water compatible, but this effect lasts only a day, making it impractical for superhydrophilic electronics. Alternatively, coating polydimethylsiloxane (PDMS) with polyvinyl alcohol (PVA) and silica nanoparticles (SiO_2) achieves long-term superhydrophilicity for unidirectional sweat transport in the HLD. Remarkably, the PVA/SiO_2 nanoparticles maintain superhydrophilicity for 30 days, demonstrating their effectiveness in surface modification. With a superhydrophilic surface, water spreads uniformly without forming droplets, promoting rapid evaporation and enhancing sweat transport to the electronic surface. Optimizing micropillar height at 100 μm balances structural stability with efficient transport.

The liquid diode's robust extraction and distribution capabilities improve adhesive strength, addressing commercial electrodes' lack of satisfactory adhesive performance and biocompatibility under high perspiration. The permeable electrodes with liquid diode mitigate these issues by rapidly eliminating perspiration (Figures 1G and 1H). Furthermore, the liquid diode has a negligible impact on biosensor sensitivity. Even postexercise, electrocardiogram readings remain clear, showing that the liquid diode can counteract perspiration's effects, ensuring consistent signal intensity and frequency (Figure 1I).

Improving biointerfacing through both passive and active transport has emerged as a key area of research. Passive liquid transport utilizes specialized structures to facilitate the process, with porosity design and hydrophilicity gradients playing crucial roles. Hollow or porous microneedles, for example, have a significant cavity volume that allows for the extraction of intestinal fluid upon insertion into the dermis layer. When combined with a glucose sensor, these microneedles can accurately detect blood glucose levels for up to 2 weeks, without causing discomfort or harm to the individual.[6] Active transport, on the other hand, requires an external energy source. In microfluid systems, directional liquid transport allows for precise control over the direction, speed, and distance of liquid movement. This can be achieved by actively pumping water through a microfluidic channel in a vibrating flow configuration, creating a gap between a single microfiber and the substrate.[7] It is worth mentioning that wearable magnetoelastic bioelectronics can convert biomechanical activities into electricity as a sustainable power source,[8] which might be harnessed to drive and enhance directional liquid transport. Since the magnetic field could penetrate water, such magnetoelastic bioelectronic devices are stable against body fluids.[8,9]

The liquid diode introduces a diverse range of biomonitoring applications, paving the way for the future design of breathable bioelectronics (Figure 1J). One application involves developing electronics that offer enhanced liquid and gas permeability, ensuring optimal comfort for wearers. Moreover, maintaining long-term adhesion to the skin ensures seamless contact, preserving the initial sensitivity of the electronics. Another application involves the integration of multifunctional sensors for additional physiological insights. For instance, wearable biosensors capable of continuously measuring sweat volume can detect impedance changes as sweat passes over the electronics. Additionally, incorporating estradiol-selective DNA aptamers into the electronics allows for the capture and detection of estradiol levels in sweat, offering a simpler alternative to traditional blood sample techniques like mass spectrometry or immunoassays. This enables easy monitoring of trace-level biomarkers at home (Figures 1K and 1L).[9] Therefore, the utilization of liquid diodes significantly enhances device comfort and provides comprehensive clinical information, showing great promise for the future of textile-based human-machine interfaces and waterproof bioelectronics.[10]

In general, the innovative use of liquid diodes greatly improves the comfort and functionality of these devices, offering expansive clinical data. It shows immense potential for advancing textile-based human-machine interfaces and waterproof bioelectronics. Through the use of a three-dimensional liquid diode, sweat is efficiently moved to the electronic device's top layer for analysis. This is achieved by exploiting hydrophilicity and a curvature gradient to create surface tension and Laplace pressure, guiding sweat droplets upward. This mechanism ensures that electronics can manage high sweat levels by redistributing moisture over the device's surface, protecting internal components from moisture damage.

Moreover, these electronics have the potential to monitor trace biomarkers in sweat for extended health monitoring. However, several challenges remain, such as (1) finding durable waterproof materials that resist sweat-induced erosion and salt corrosion, (2) optimizing sweat transport to balance extraction and skin hydration, and (3) developing compact sweat biosensors for multibiomarker detection. Future research could focus on integrating 5G and the Internet of Things to improve access to medical care, presenting an exciting frontier for wearable health technology.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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