Wearable Sweat Sensors with Battery-Free Osmotic Pumping

Sweat and interstitial fluid (ISF) contain a wide variety of essential biomarkers and can be important sources of information for monitoring an individual's health. Wearable devices and assays that collect sweat and monitor biochemicals constitute a rapidly expanding multibillion-dollar market. However, collecting such fluids for continuous long-term analysis is challenging because most of the commercially available health-monitoring devices are either invasive (or semi-invasive) in nature or work only during active sweating, while patients are undergoing strenuous physical exertion.

A collaborative team at North Carolina State Univ. (NCSU) led by chemical engineers Orlin Velev and Michael Dickey has introduced a unique sweat and ISF collection technique that overcomes these challenges. The team is part of the Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST), one of the National Science Foundation's (NSF's) Engineering Research Centers (ERC). Their technique can achieve long-duration operation by a novel non-invasive osmotic method that requires no external power and works during passive sweating.

The team has demonstrated the viability of the technique by constructing a wearable paper microfluidic patch for sweat sampling and lactate analysis that can function under low-sweating conditions without requirement of any physical exertion. The patch combines the action of three basic effects: osmotic microfluidic pumping between skin and a hydrogel disk, capillary wicking through paper, and evaporation-assisted fluid management.

The osmotic extraction is based on a simple premise — the difference in the chemical potential created by the hydrogel gently pulls the biological fluid from the skin. The extracted sweat and biomarkers are wicked through the paper strip toward the evaporation pad. This sweat can be analyzed by a variety of sensing modalities (colorimetric, electrochemical, etc.). The evaporation of both the osmolyte and the sweat with biomarkers leads to accumulation of the non-volatile components of the sweat on the pad, and additionally creates a record of all bioanalytes present in the sweat.

The patches can sustain continuous sweat sampling from hours to days. Testing shows that the patch is able to detect lactate and potassium ions. With help from electrical engineer Alper Bozkurt's group at NCSU, the team has recently demonstrated completely wireless long-term lactate sensing.

Further, in collaboration with electrical engineer Michael Daniele's group at NCSU, Velev and Dickey have shown that the technology is also well-suited for long-term continuous extraction of ISF. The ISF, which is another source of rich biochemical information, is extracted with the help of microneedle patches that penetrate the top skin layer. The osmotic technique enables long-term ISF extraction, pumping, and analysis on paper microfluidics without the need to exchange the microneedle patches.

This technology can be used in new generations of wearable bioassays and health-status monitoring devices that can sustain extended operation with inexpensive replaceable patches. The hydrogel-paper patches can also be used in simple non-invasive skin assays for affordable at-home testing. The patent-pending technology is available for commercialization in new types of wearables. CEP

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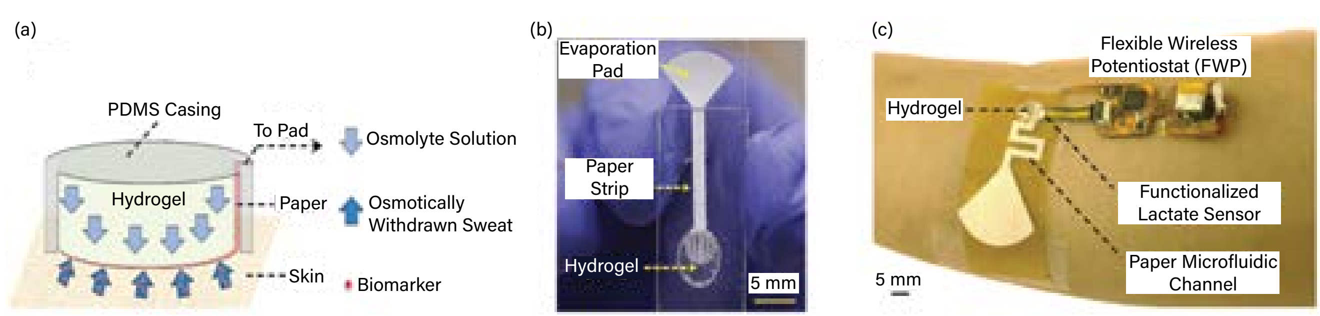

▲ (a) The hydrogel disc facilitates osmotic extraction of sweat. (b) Sweat is wicked along a paper strip and evaporation occurs at the terminal pad. (c) Sensors can be placed along the paper strip to detect bioanalytes that pass by during extraction. The integrated device for long-term lactate sensing includes a flexible wireless potentiostat mounted on the forearm using an adhesive patch.

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