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Non-invasive hormone monitoring with a wearable sweat biosensor

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Wearable sweat biosensors enable the non-invasive, real-time monitoring of hormones. Here, we highlight the development and commercialization of a wearable technology that can measure hormone levels in sweat for women's health applications, including fertility tracking and menopause management.

Hormones are integral in women's health, influencing reproduction, mood, bone density, cardiovascular health and cognition. In particular, the oestrogen oestradiol regulates many of these processes, alongside other hormones, such as progesterone and testosterone[1]. Accurate hormone monitoring is crucial for managing fertility, menopause and hormone replacement therapy. However, current methods are invasive, time-consuming and often impractical for daily use. In our start-up company Persperity Health, we have designed a wireless wearable sweat-sensing technology for real-time and non-invasive hormone monitoring (Fig. 1a).

The need for comprehensive hormone monitoring

Convenient and accurate hormone monitoring tools remain scarce. Most current methods rely on clinical blood draws or at-home kits requiring 24-hour urine or saliva samples, which must be mailed to a laboratory for analysis[2]. Although these methods can offer snapshots or a general view of hormonal health, they often fail to capture the dynamic nature of hormonal fluctuations, which can vary substantially day-to-day and even hour-to-hour.

For fertility tracking, real-time hormone data is essential. Oestradiol levels rise during the follicular phase, peaking just before ovulation and declining afterward, signalling peak fertility[3]. This crucial window is often missed with currently available monitoring methods. In addition, individuals undergoing menopause or hormone replacement therapy require regular hormone monitoring to manage symptoms, such as hot flashes, osteoporosis and cardiovascular risks. Inaccurate or infrequent hormone monitoring can lead to improper drug dosing and adverse health outcomes. Moreover, accurate hormone tracking is required in conditions such as polycystic ovary syndrome, endometriosis and menstrual migraines.

Challenges in hormone detection

Developing non-invasive hormone monitoring technology presents both scientific and practical challenges[2]. Oestradiol circulates in the blood at concentrations in the range of hundreds of picomolar, and its levels in sweat, although correlating with blood levels, are approximately 50 times lower, primarily owing to the selective and limited transport of the hormone through sweat glands and its dilution in the aqueous sweat matrix[4]. The detection of such low quantities demands sensitive and specific sensing technology. Moreover, sweat composition can vary based on hydration, diet and environmental factors.

User adoption also plays a key part. For example, for fertility tracking, ease-of-use, affordability and actionable insights should be considered. By contrast, clinical applications, such as hormone replacement therapy monitoring, require devices to meet regulatory standards, demonstrate consistent performance across diverse populations and establish strong correlation between sweat and serum hormone levels. Large-scale clinical trials are essential to secure regulatory approval, adding financial and logistical hurdles.

Hormone monitoring in sweat

Sweat offers a promising non-invasive alternative to blood and urine for hormone monitoring. It is easily accessible, painless to collect and rich in biomarkers, such as electrolytes, metabolites and hormones[5–8]. Unlike blood draws, sweat sampling avoids discomfort, making it well suited for frequent or continuous monitoring.

Urine and saliva can also be non-invasively sampled, but their point-of-care analysis often yields only qualitative results. In addition, saliva can be affected by food intake, hydration and oral bleeding, reducing accuracy. Sweat, by contrast, provides a more consistent sampling matrix, enabling real-time hormone analysis without external interference.

To address the variability of sweat production, we apply iontophoresis, a method that uses mild electrical currents to deliver cholinergic agents (for example, carbachol) beneath the skin, inducing localized sweating that can be sampled with microfluidics[9]. This ensures consistent sample collection, even during rest, eliminating the need for exercise or heat exposure to produce sweat.

Wearable sensor technology for real-time hormone tracking

To meet the high sensitivity and specificity requirements, the wearable platform by Persperity Health uses a strand-displacement aptamer-based electrochemical nanosensor to detect picomolar concentrations of hormones in sweat[4] (Fig. 1b). Aptamers are synthetic single-stranded DNA (ssDNA) molecules engineered to specifically bind to target molecules, offering cost-effectiveness, stability and high specificity[10]. These aptamers are immobilized on a gold nanoparticle-coated surface, enhancing surface area and increasing aptamer loading capacity for improved sensitivity.

When the target hormone binds to the aptamer, it triggers a conformational change, displacing a redox probe-tagged ssDNA. The displaced ssDNA binds to complementary strands on a nearby printed gold nanoparticle-MXene-based working electrode, which offers high electron transport efficiency. This interaction produces a distinct electrical redox signal on the working electrode, directly correlating with the hormone concentration. The low-background-noise 'signal-on' approach enables highly sensitive hormone detection within the picomolar range.

To address the challenge of the sweat rate influencing the diffusion of displaced ssDNA to the working electrode, capillary bursting valves are implemented in the microfluidic design of the fully integrated wearable sensor system (Fig. 1b,c). These valves regulate sweat flow and stabilize sample volumes, ensuring consistent measurement within a quiescent sample matrix. Additionally, to correct for inter- and intra-individual variability in sweat

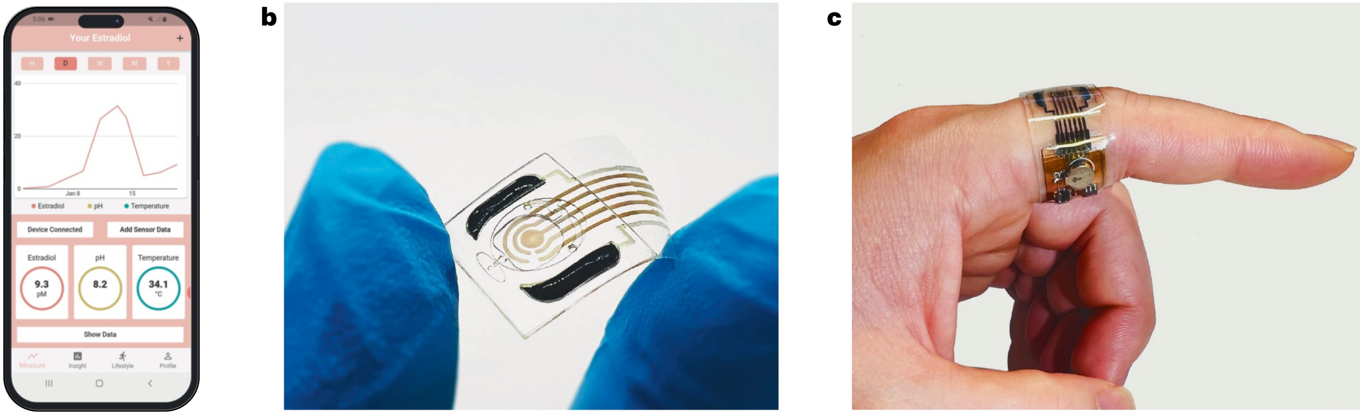

Fig. 1 | Non-invasive hormone monitoring using a wearable sweat sensor. **a**, A mobile interface allows wireless communication with the wearable sensor and real-time oestradiol level tracking. **b**, Flexible microfluidic oestradiol sensor patch. **c**, Fully integrated wireless wearable sensor. Figure adapted from ref. 4, Springer Nature Limited.

composition, real-time calibration sensors for pH, ionic strength and temperature are integrated, ensuring reliable measurements. Inkjet printing of the electrode further allows scalable low-cost production, making the system viable for widespread deployment.

Commercialization challenges

A key challenge in the commercialization of this technology is the scale-up of manufacturing to produce consistent, high-quality sensors at low cost. Scale-up requires microfabrication, precise electrode printing, receptor modification and robust quality control. Achieving uniformity in sensor response is crucial, as inconsistencies in fabrication can compromise the accuracy of hormone measurements.

Additionally, the inherent variability of sweat presents obstacles to reliable, day-to-day and person-to-person correlations. Factors such as hydration, diet and environmental conditions can affect sweat composition. To address this, we integrate real-time calibration mechanisms to measure sweat pH, impedance and temperature. Furthermore, clinical studies will be conducted to obtain large datasets and refine the algorithms of the platform, enhancing its predictive accuracy and minimizing variability.

Another key challenge is navigating regulatory pathways, particularly for clinical applications, such as hormone replacement therapy. Regulatory agencies demand comprehensive data demonstrating accuracy, reliability and safety. This necessitates large-scale validation studies across diverse populations to establish sweat–blood hormone correlations. We collaborate with healthcare institutions to conduct these trials, aiming to meet the requirements set by the US Food and Drug Administration.

Finally, market positioning needs to be considered. For direct-to-consumer products, affordability, ease of use and accuracy need to be balanced. Building partnerships with healthcare providers and securing clinical endorsements will help to integrate the technology into mainstream care.

Expanding market potential

Although fertility tracking is the initial focus, this technology might also be applied to other areas. For example, biomarkers, such as progesterone, testosterone and cortisol, could be measured to monitor various hormonal and metabolic conditions.

In addition, real-time multiplex hormone detection could aid in menopause management by enabling the optimization of hormone replacement therapy, management of symptoms and mitigation of long-term risks, such as osteoporosis. The platform could also aid in the early detection and treatment of polycystic ovary syndrome, endometriosis and hormonal pain conditions. By monitoring cortisol and substance P, the device may further extend into stress and chronic pain management. Moreover, this technology could find use in monitoring sports performance, metabolic health and stress management.

We envision hormone monitoring as seamlessly integrated into daily life, similar to checking heart rate. Efforts to miniaturize the technology into adhesive patches or smart rings are underway, enabling continuous, unobtrusive monitoring.

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Author contributions

Y.L. and W.G. co-authored the manuscript, reviewed it and approved the final version.

Competing interests

W.G. is co-founder and advisor at Persperity Health.