Posted: Sep 26, 2017

Lab-on-skin: Nanotechnology electronics for wearable health monitoring

(*Nanowerk Spotlight*) Nanotechnology materials are going to open new realms of possibility for flexible and stretchable monitoring gadgets that are wearable directly on the skin. In our previous Nanotechnology in Healthcare Spotlight we already looked at some – even futuristic – biofunction monitors.

A new review in *ACS Nano* ("Lab-on-Skin: A Review of Flexible and Stretchable Electronics for Wearable Health Monitoring") looks at the latest developments in a class of electronic devices, commonly referred to as *electronic skin*, *epidermal electronics*, or *electronic tattoos*, from the materials, devices, and medical applications perspectives.

While such devices can also be used for prosthetics and rehabilitation, optogenetics, and human-machine interfaces (HMI), this review focuses on the properties of the materials that enable skin-mounted sensors for use as diagnostic tools in the medical field.

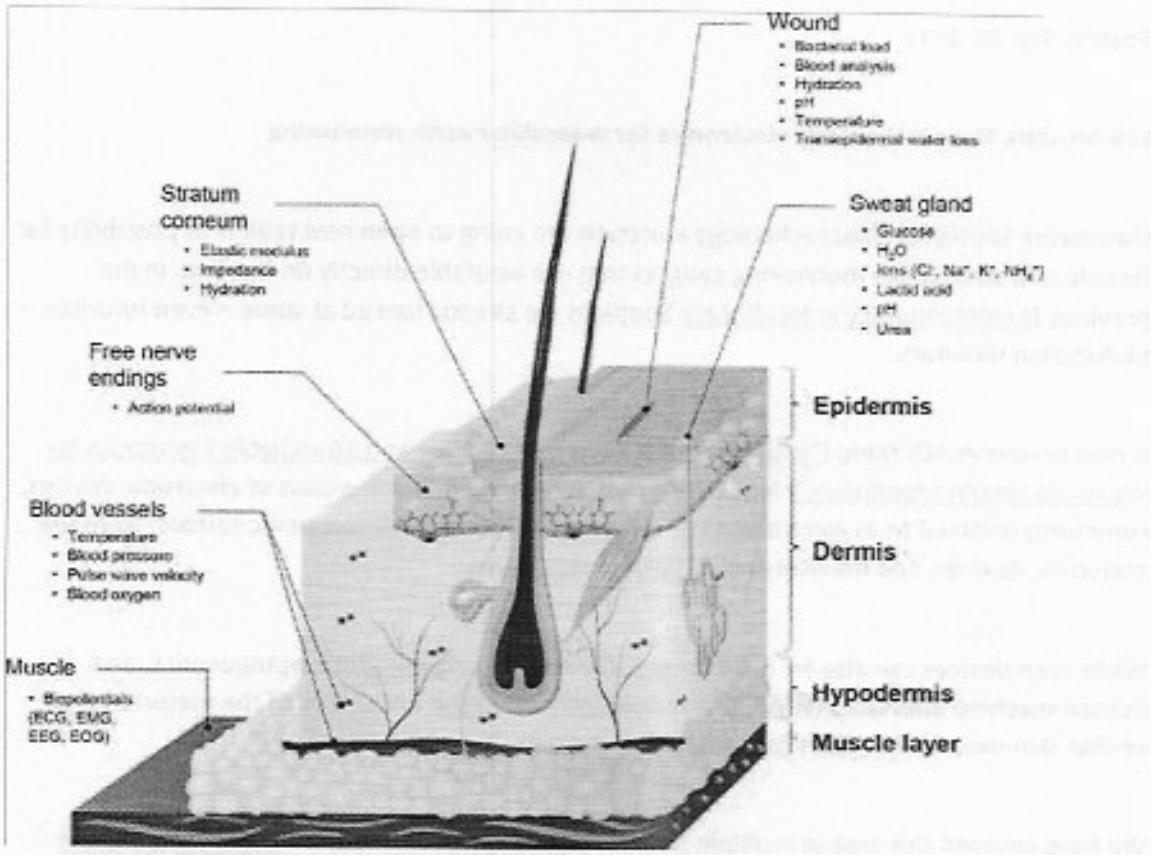
We have covered this area in multiple *Nanowerk Spotlights*, for instance stick-on epidermal electronics tattoo to measure UV exposure or tattoo-type biosensors based on graphene; and we also have posted a primer on electronic skin.

In this latest review, after reviewing the latest developments in designs, materials, powering, and skin-integration strategies, the authors provide recent examples of devices for potential clinical applications in cardiology, dermatology, electrophysiology, and sweat diagnostics.

The paper concludes with an overview of current challenges and possible future directions on wireless powering and communication, seamless skin integration, and application-specific design.

A lab-on-skin takes advantage of the fact that the skin is the largest organ of the human body and an ideal surface for unobstructed access to vital biological signals from inner organs, blood vessels, muscles, and the dermis and epidermis.

Indeed, skin can be regarded as a signal source: It can both generate and transmit biological signals that provide important health metrics of an individual. The figure below shows the primary biosignal sources in the skin anatomy and the typical physiological information available for sensing.



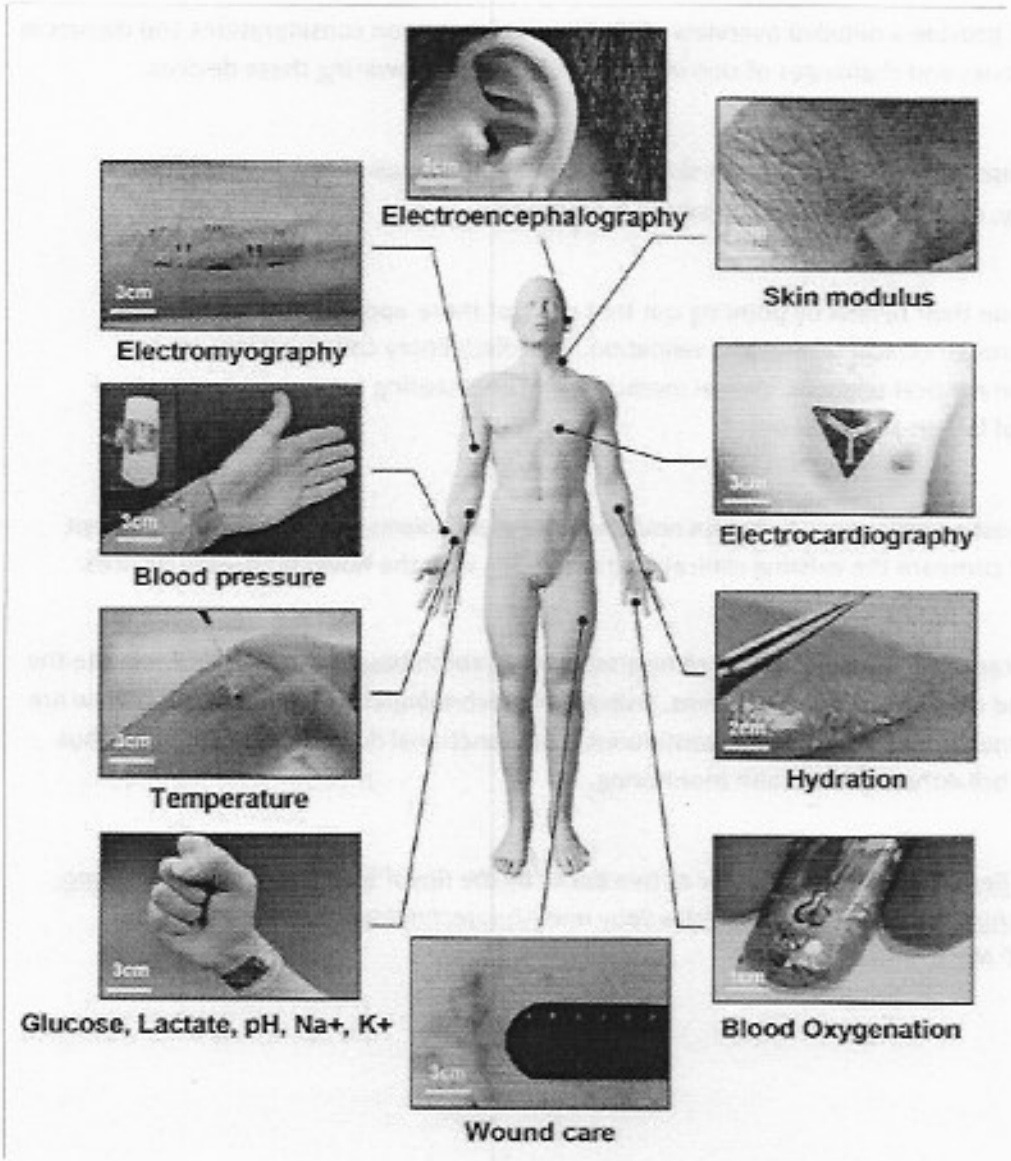
Skin as a diagnostic platform. Diagnostic signals from muscles, blood vessels, free nerve endings, stratum corneum, wounds, and sweat glands. (© ACS) (click on image to enlarge)

The concept of a lab-on-skin, introduced in this review paper, describes a set of soft, flexible, and stretchable electronic devices, which conformally contact with the epidermis to deliver a range of functionalities, thereby resembling a clinical laboratory.

The underlying concept is that these lab-on-skin devices can noninvasively measure most of the biometrics required for health monitoring and disease diagnosis.

The robust and soft contact between the flexible/stretchable devices and the skin enables continuous, long-term, and accurate sensing, which is difficult to obtain with conventional wet electrodes due to their propensity for drying out.

The figure below shows examples of soft electronic interfaces developed for both monitoring and diagnostic functions at various locations on the human body.



A lab-on-skin. Stretchable and flexible electronic devices as biosensors for measuring (clockwise from top right) skin modulus, electrocardiology, hydration, blood oxygen, wound-healing rate, sweat content, skin surface temperature, blood pressure, electromyography, and electroencephalography. (© ACS) (click on image to enlarge)

Such devices provide tools to measure physiological status including temperature, hydration, blood pressure, blood oxygen level, skin mechanics, wound-healing, electrophysiology, and various biomarkers in sweat. Applications could span from dermatology, cardiology, neurology, and hematology to urgent care.

For example, electrophysiological signals such as ECG provide detailed information on the activity in the ventricles and atria for cardiac disease; EEG shows electrical activity in the brain for studies of sleep apnea, epilepsy, and other neurological disorders; and EMG assesses nerve and muscle health. Multifunctional sensing designs further extend this idea of a lab-on-skin.

The authors provide a detailed overview of design and fabrication considerations and discuss in detail the issues and challenges of skin integration as well as powering these devices.

They then discuss examples of lab-on-skin devices that offer applications in cardiology, dermatology, electrophysiology, and sweat diagnostics.

They conclude their review by pointing out that none of these applications will be viable without thorough clinical testing and validation. Interdisciplinary collaborations among individuals in medical sciences, clinical medicine, and engineering are crucial for practical realization of lab-on-skin systems.

Niche diagnostic applications based on novel sensing mechanisms require proof-of-concept studies that compare the existing clinical gold standards with the novel fabricated devices.

Likewise, large-scale clinical studies are necessary to establish baseline signals and validate the accuracy and reliability of these systems. Overall, the technologies described in this review are primed to enable a lab-on-skin with continuous, multifunctional diagnostic capabilities, thus providing a breakthrough in health monitoring.

By Michael Berger – Michael is author of two books by the Royal Society of Chemistry: Nano-Society: Pushing the Boundaries of Technology and Nanotechnology: The Future is Tiny.
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