

Soft Epidermal Biosystems with Advanced Sensing and Microfluidic Capabilities

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Sweat Biomarkers Enable *in situ* Monitoring



Sports Performance



Disease Screening
(Cystic Fibrosis)



Drug Testing



Fatigue/Dehydration



Heart Failure



Head Trauma

Miniaturization Enables Portable Use Cases

Conventional Method



Macroduct®



Chlorocheck™

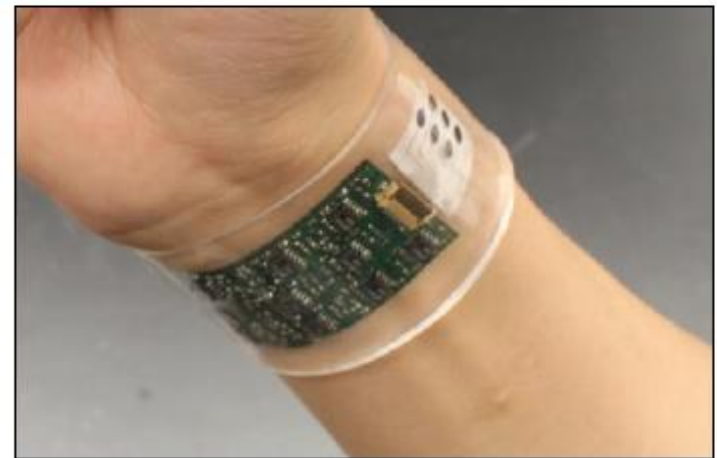


PharmChek®



LCMS

Wearable sweat sensor



Gao et al, Nature, 2016

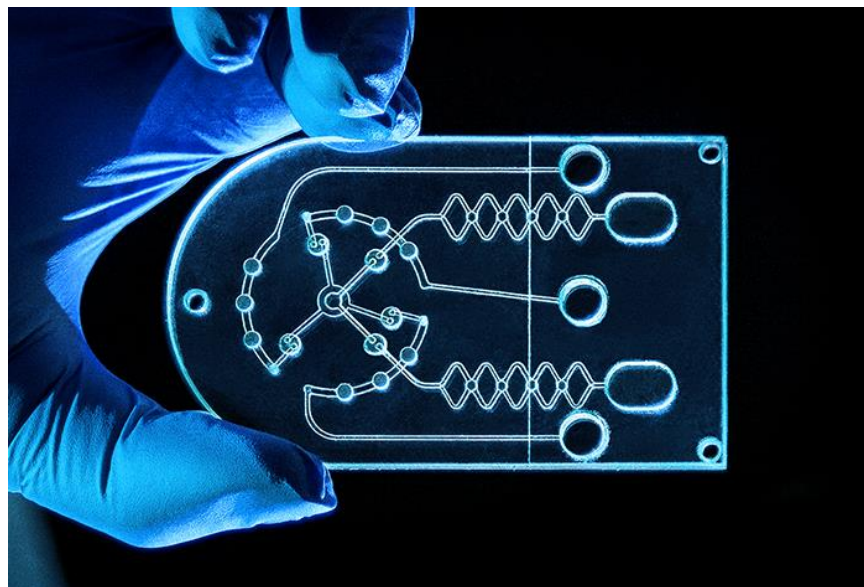
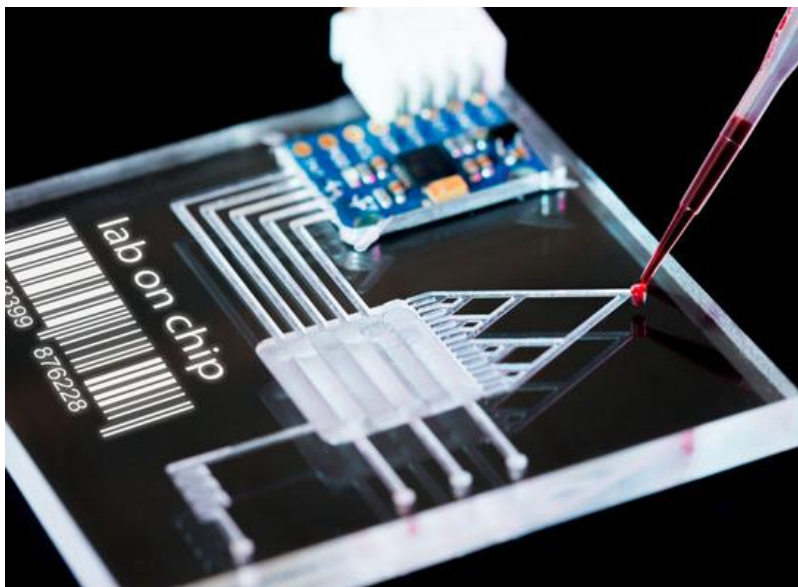
Electrochemical based
wearable sweat sensor

Inspiration: Soft Materials and Mechanics



- Thin
- Flexible
- Cheap
- Location-agnostic

Inspiration: Microfluidic Technologies

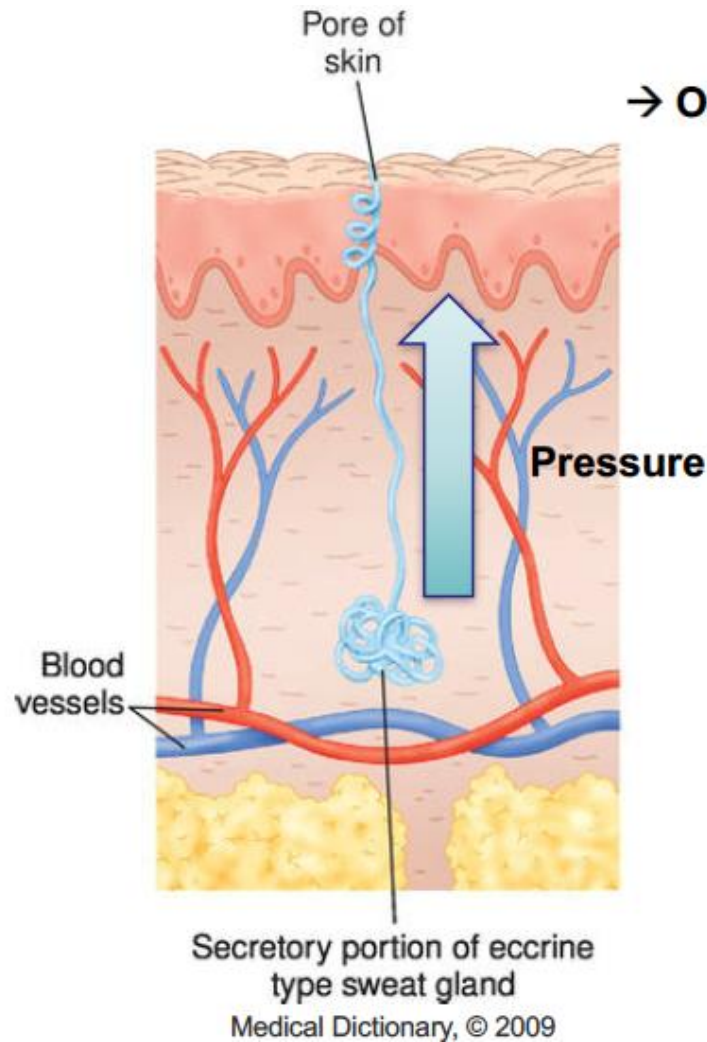


- Small sample volumes
- Highly controlled flow
- Design flexibility
- Multiplexed analysis

BUT...

- Rigid, planar, off-body
- External pumps, tubing
- External power supply
- Microscopy

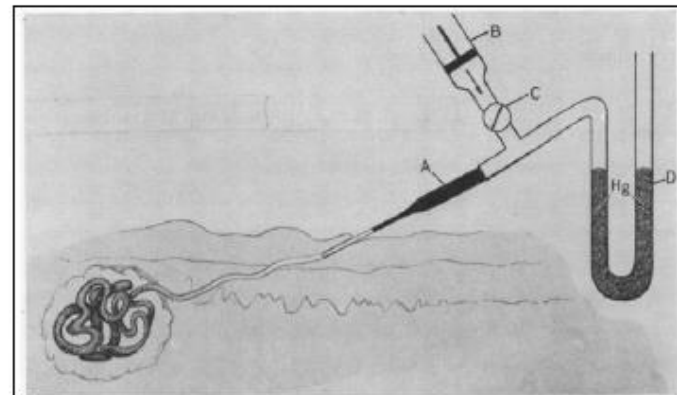
The Body Has Natural Pressure Source: Sweat Glands



Pressure source of sweat gland
→ Osmotic pressure between **plasma** and **sweat**

$$P = \sigma RT \Delta C$$

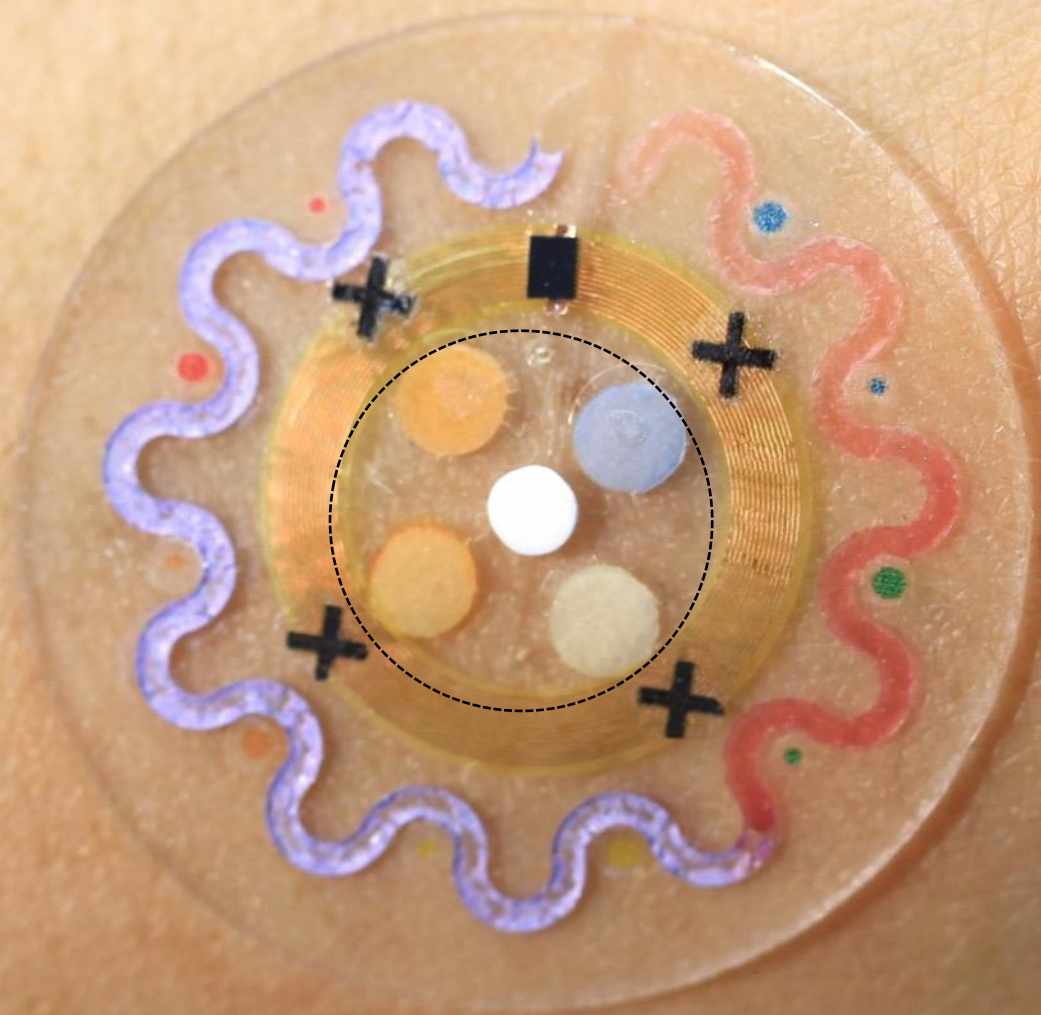
ΔC : the difference in concentration between plasma and sweat, osmolality.



Measuring sweat pressure in the duct
in 1969 → Maximum value : 72 kPa

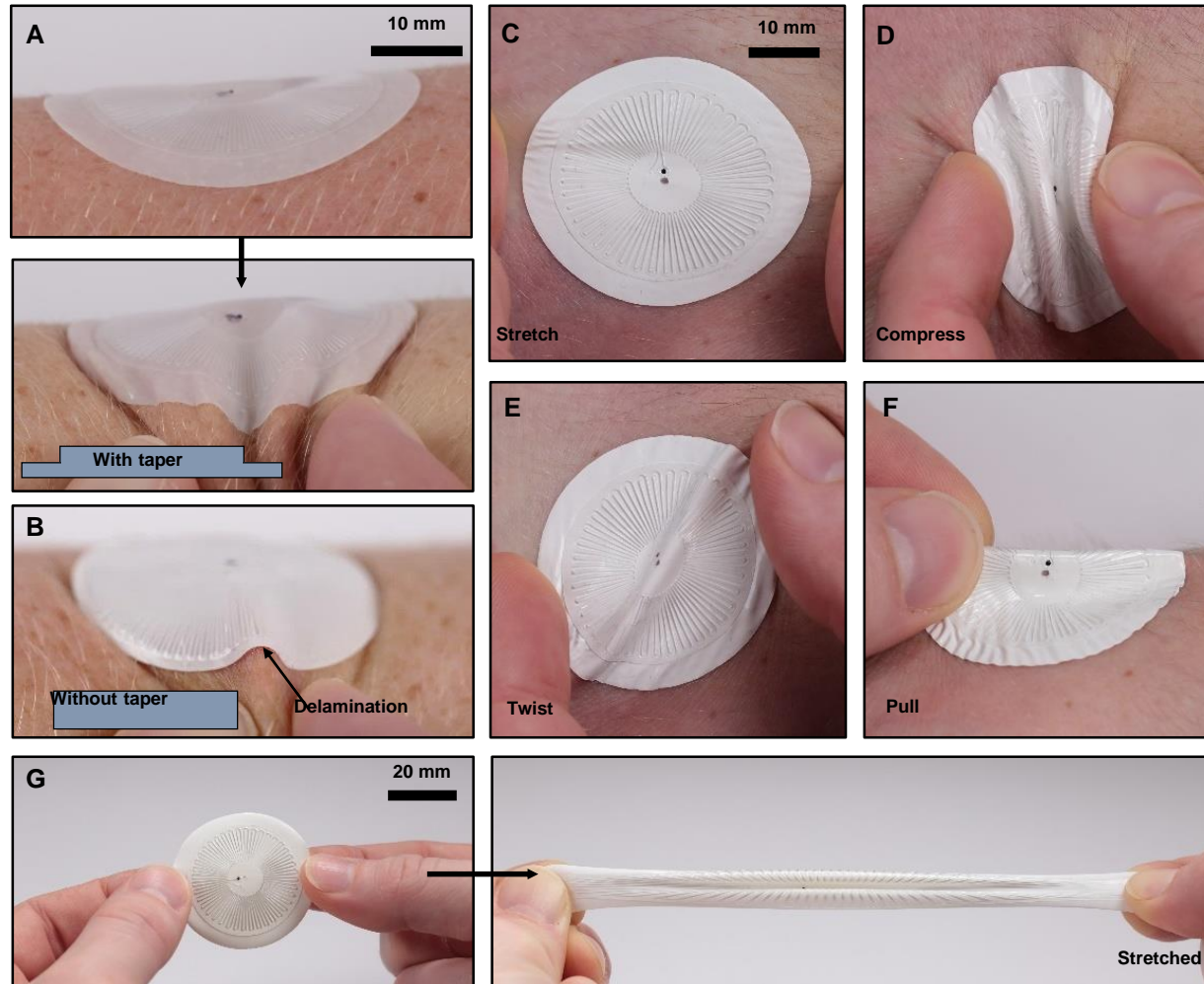
Schulz, I. J. *J. Clin. Invest.* (1969).

Epidermal Microfluidics – ‘Epifluidic’ Devices



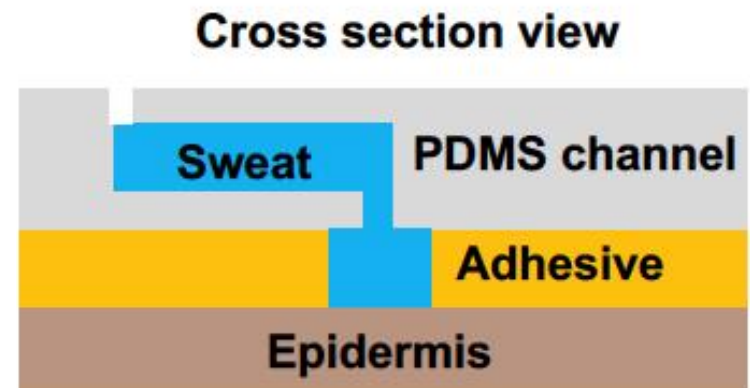
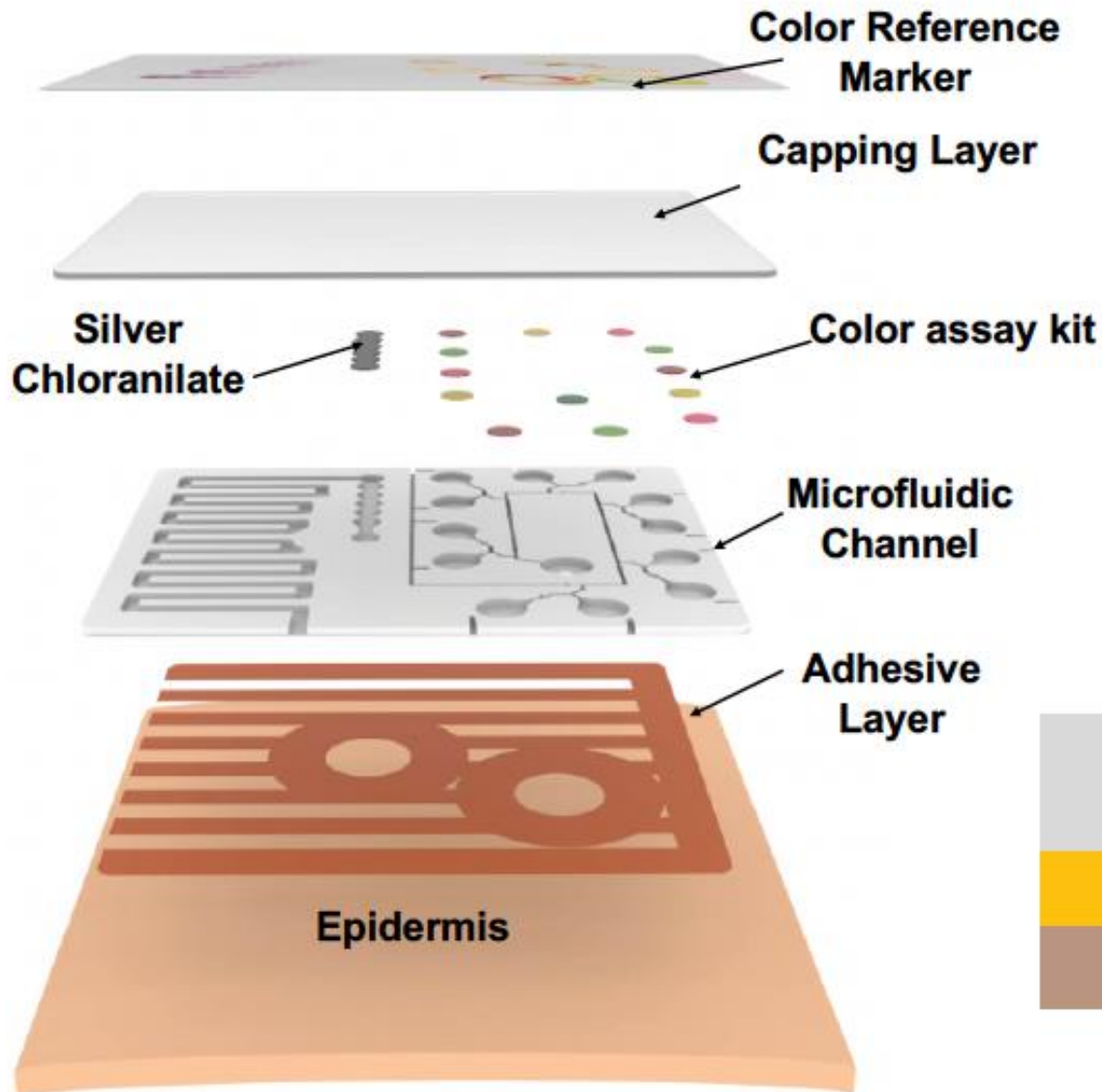
1 cm

Soft Mechanics and Ultrathin Geometries

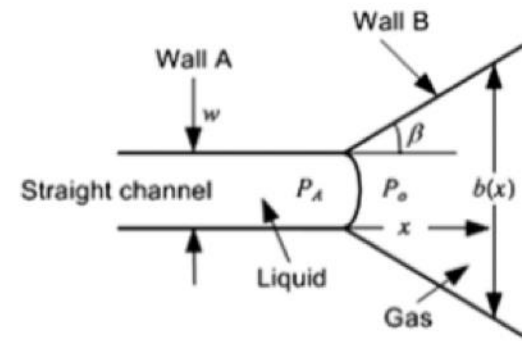
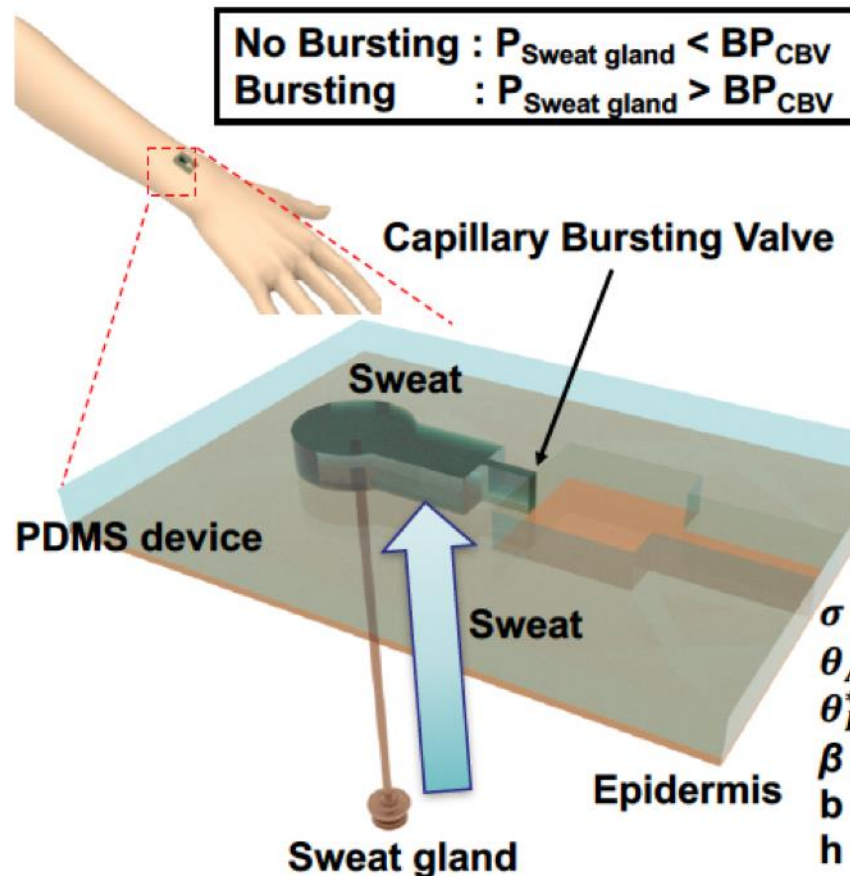


Reeder et al, in review

Multi-Layer Engineered Platform



Capillary Burst Valves to Control Sweat Flow



Capillary Bursting Pressure

$$\text{Bursting Pressure} = -2\sigma \left(\frac{\cos\theta_I^*}{b} + \frac{\cos\theta_A}{h} \right)$$

σ : surface tension of liquid

θ_A : contact angle of the channel

θ_I^* : $\min[\theta_A + \beta; 180^\circ]$

β : diverging angle of the channel

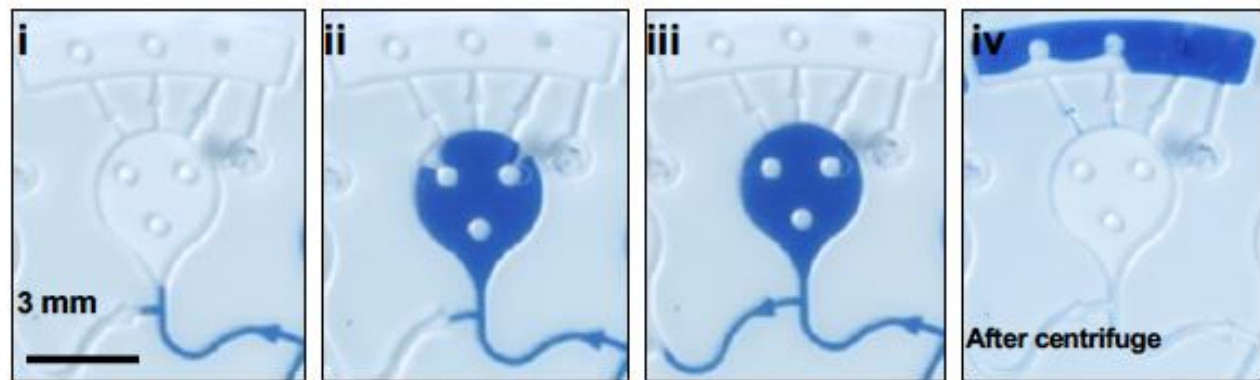
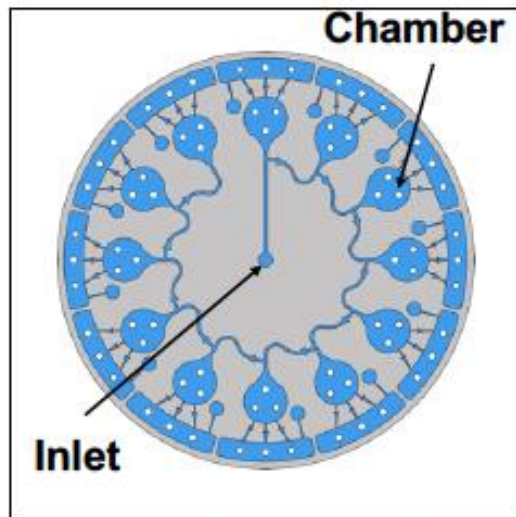
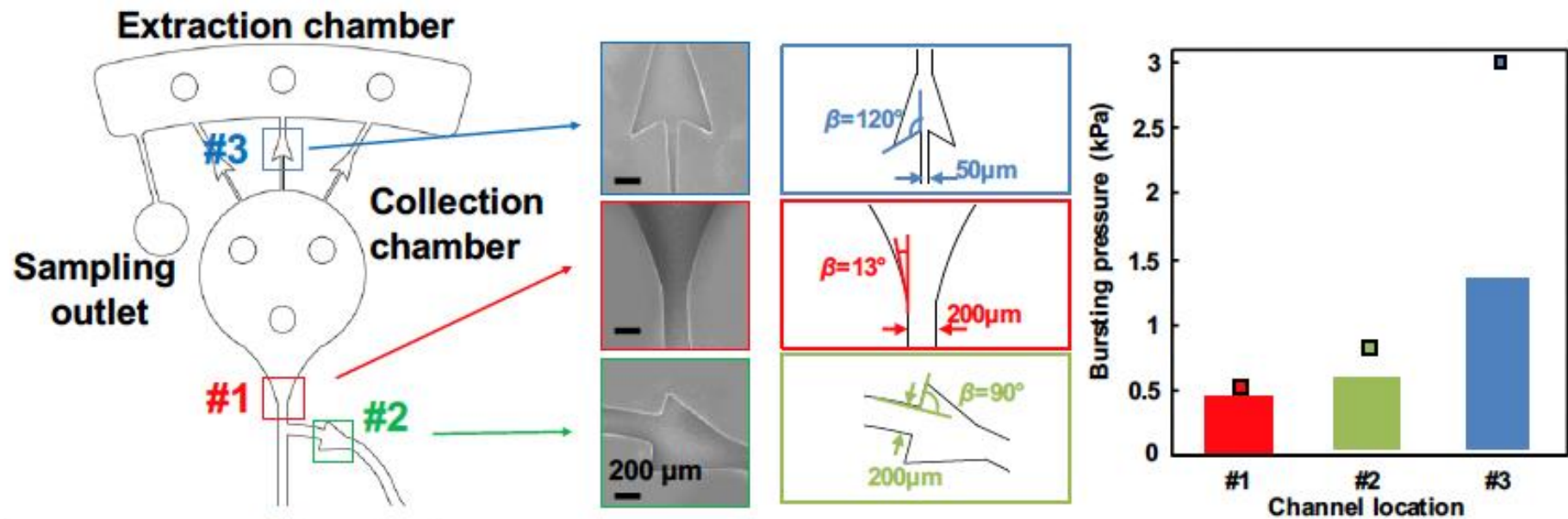
b : width of the diverging section

h : height of the diverging section

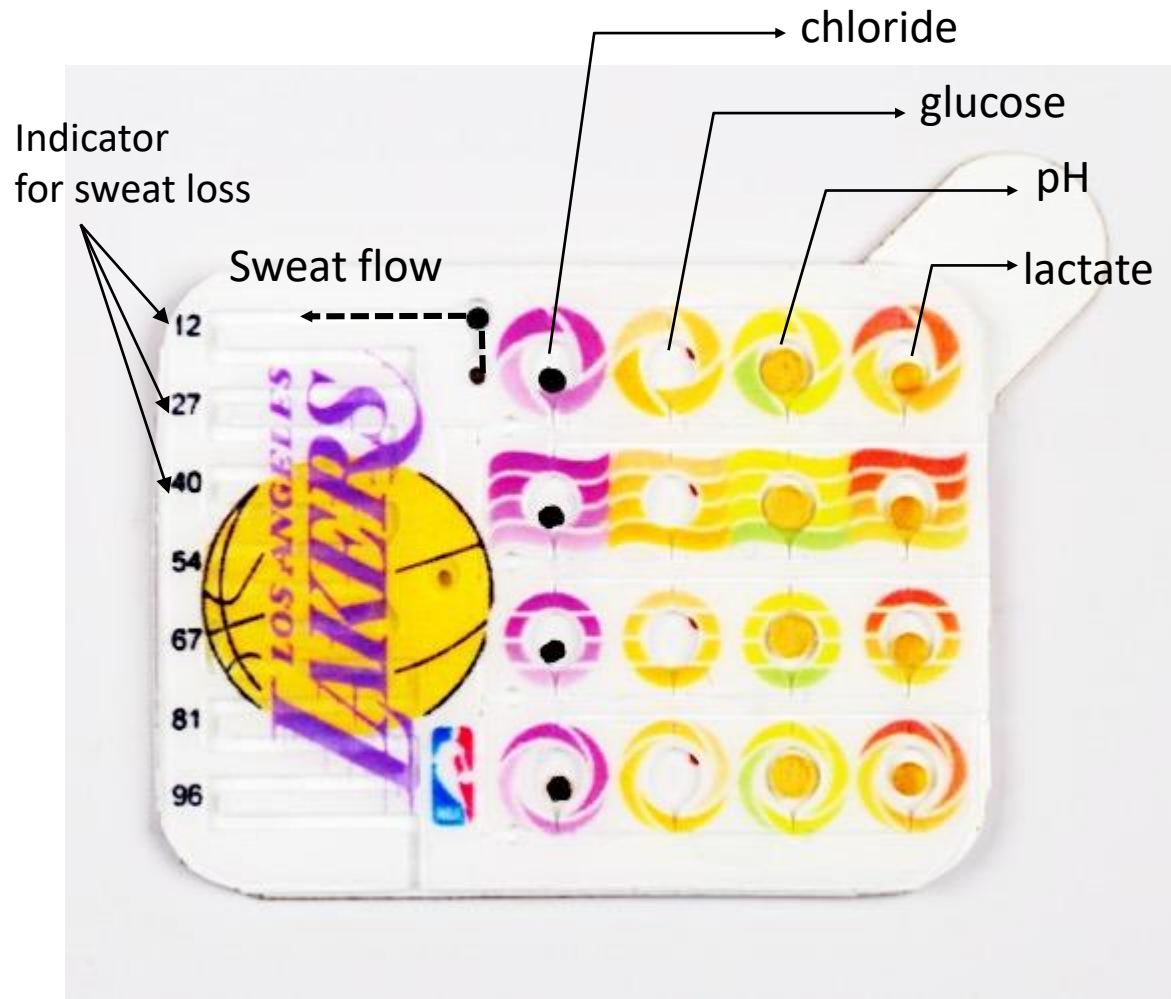
Lab on a Chip (2017).

*Not in scale

Capillary Burst Valves Allow Time-Series Sweat Sampling



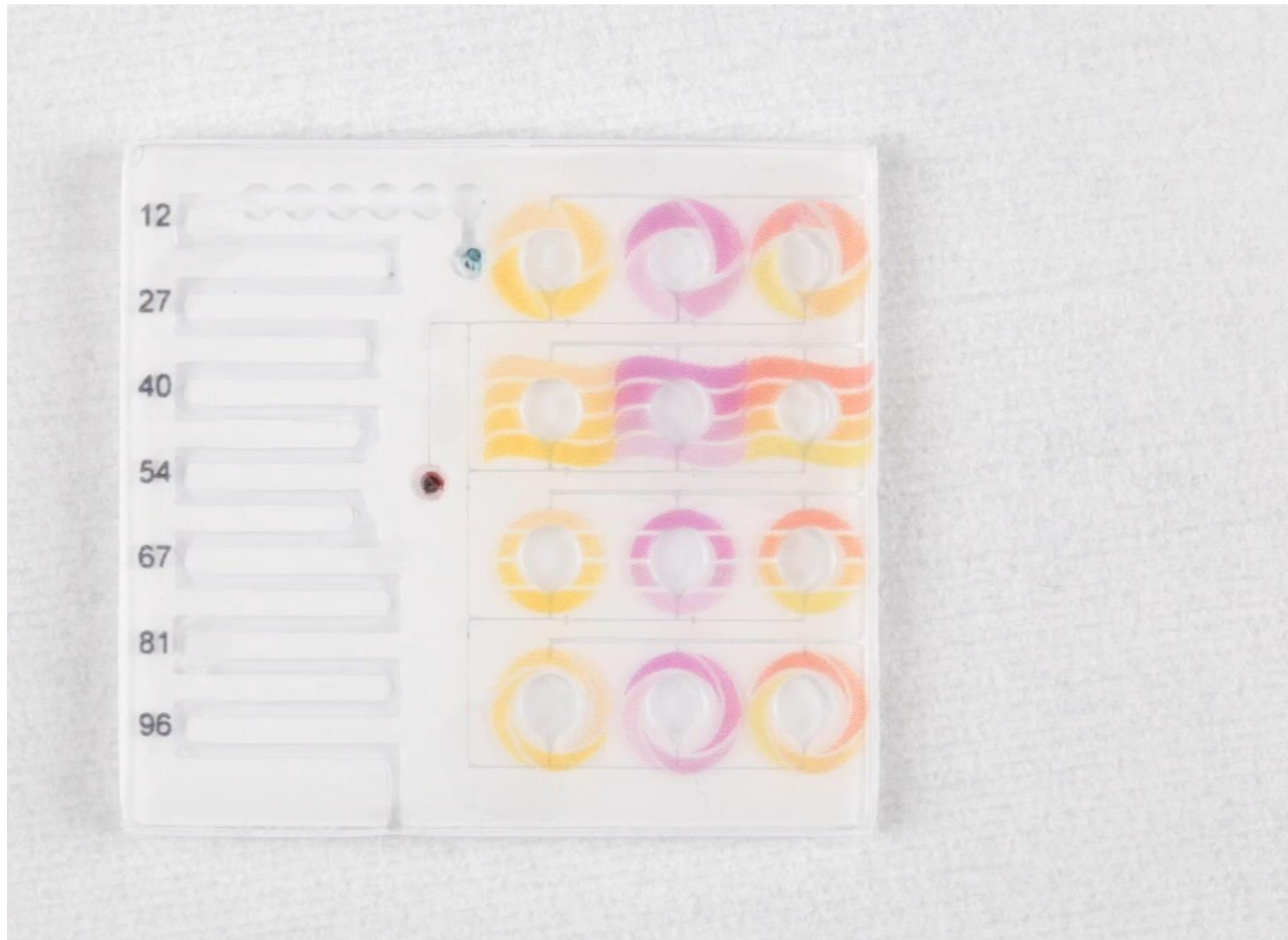
Multimodal Epifluidic Designs



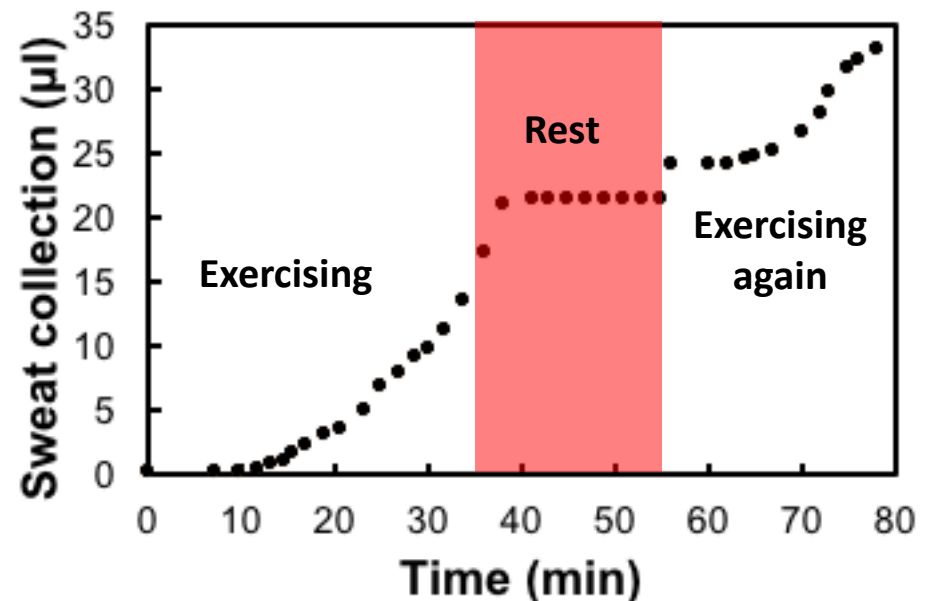
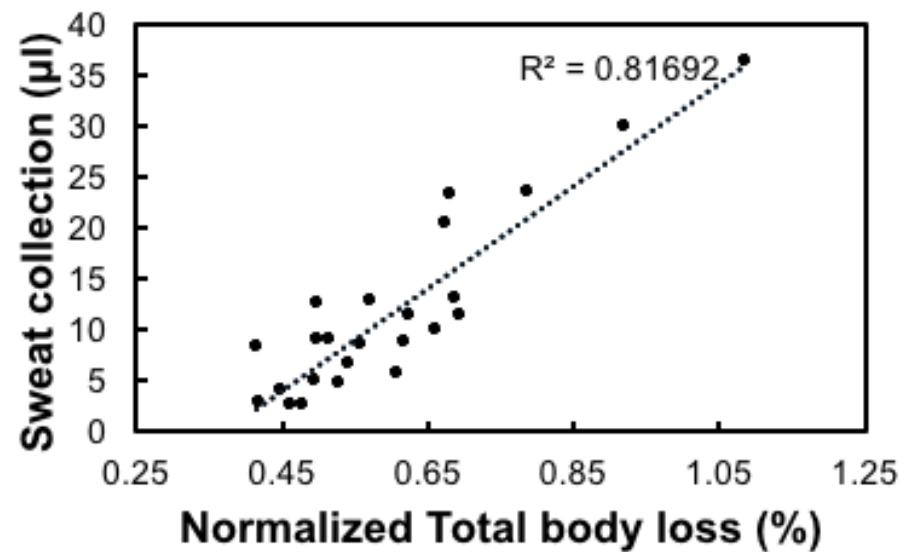
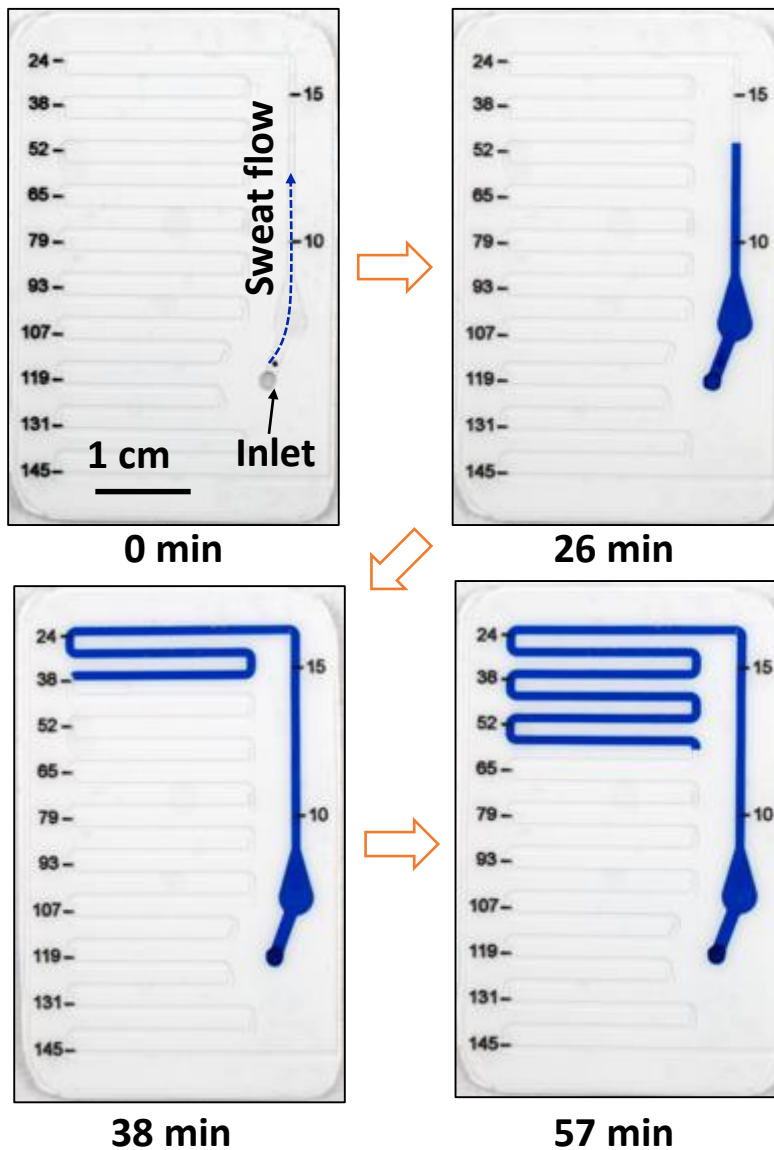
Functionality:

- Sweat loss/Sweat rate
- Electrolyte concentrations
 - Chloride
 - Glucose
 - pH
 - Lactate

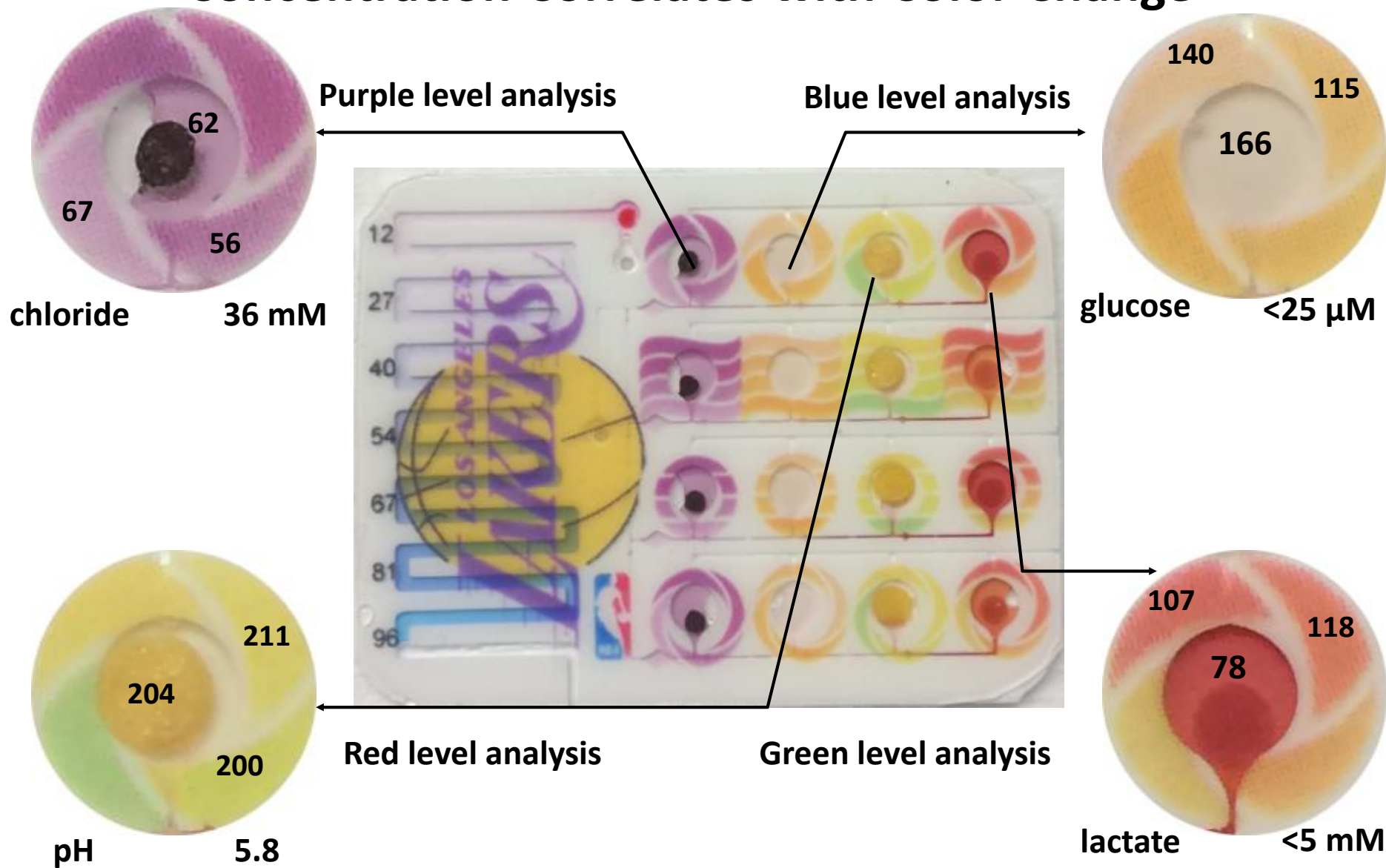
Video: Sweat Flow Through Epifluidic Microchannels



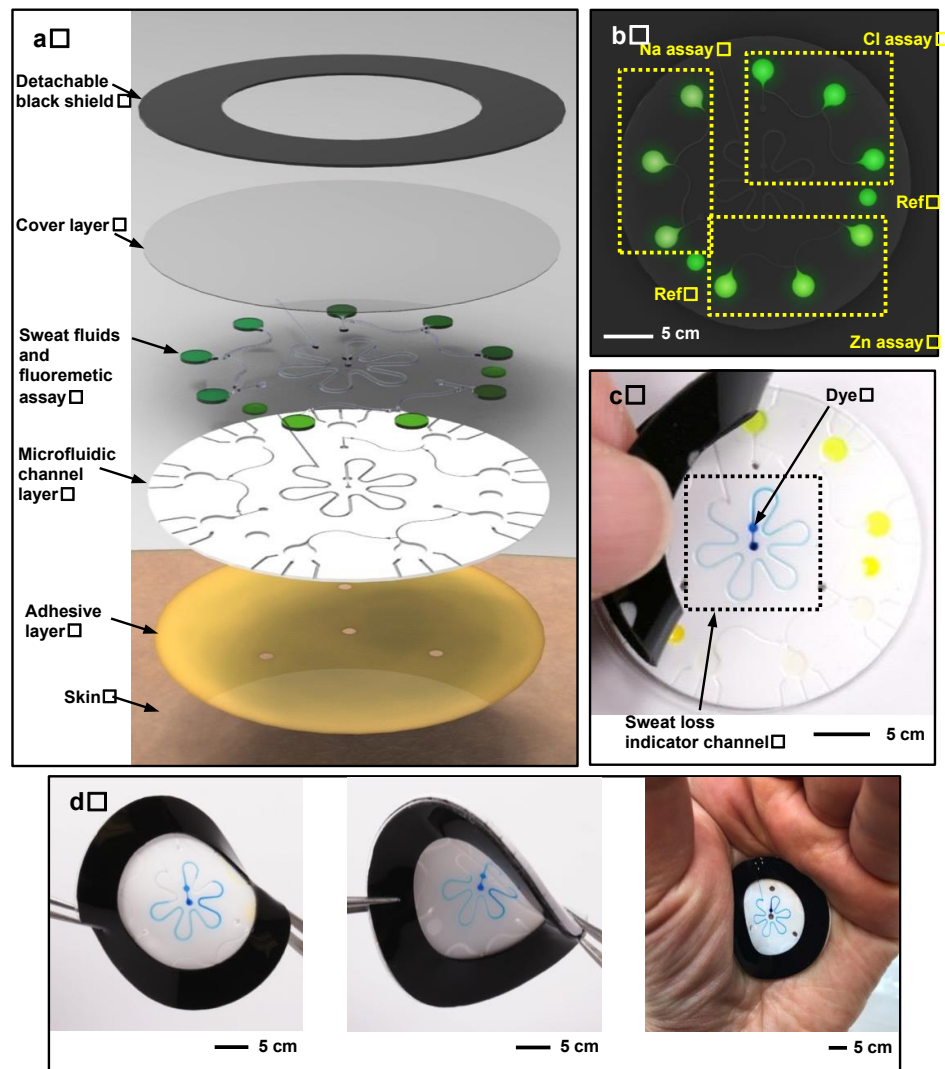
Sweat Loss and Instantaneous Rate Analysis



Concentration Correlates with Color Change



Fluoroscopic Imaging Capability Integrated Onboard Epifluidic Devices



Sekine et al, Lab Chip 2018

Smartphone Based Fluorometric Imaging

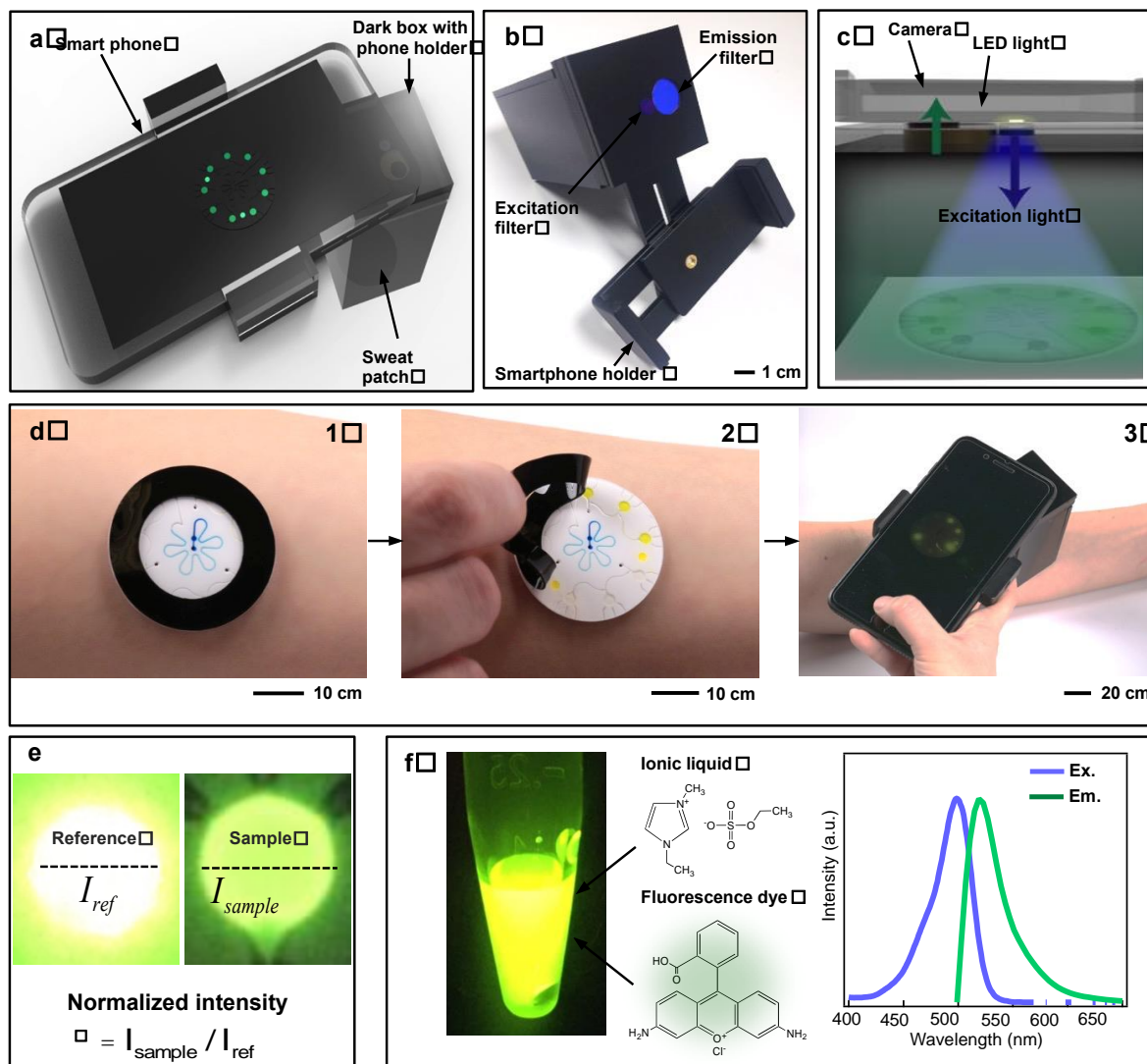
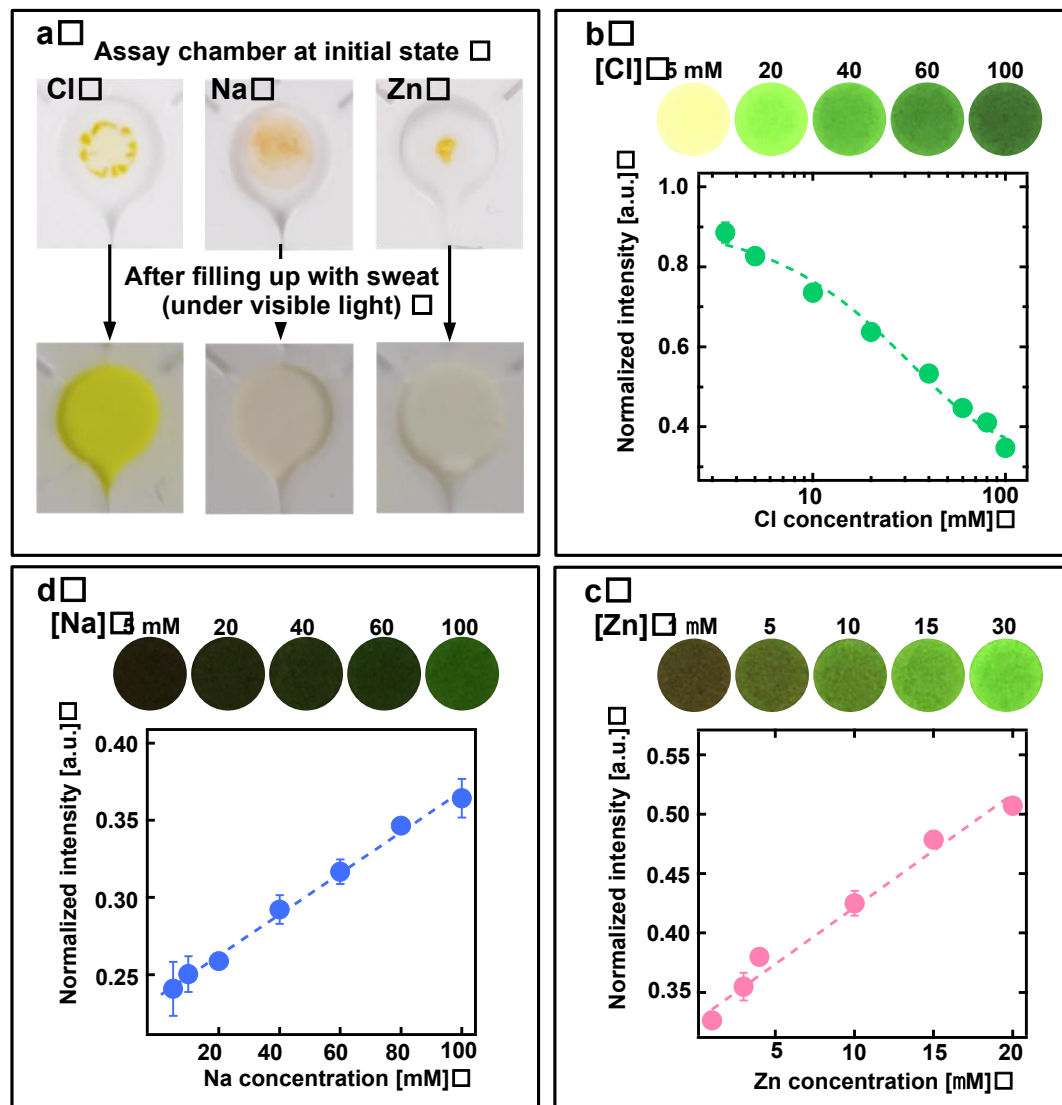
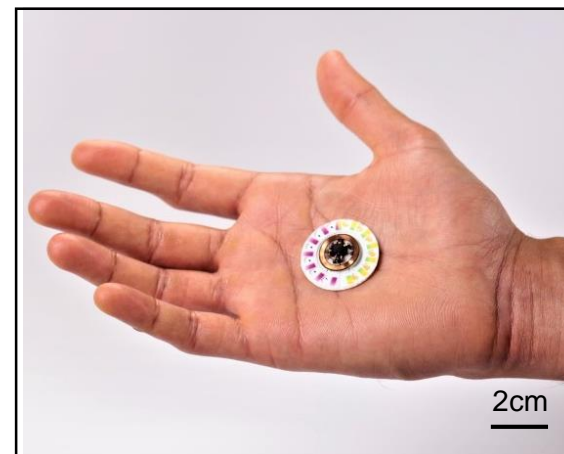
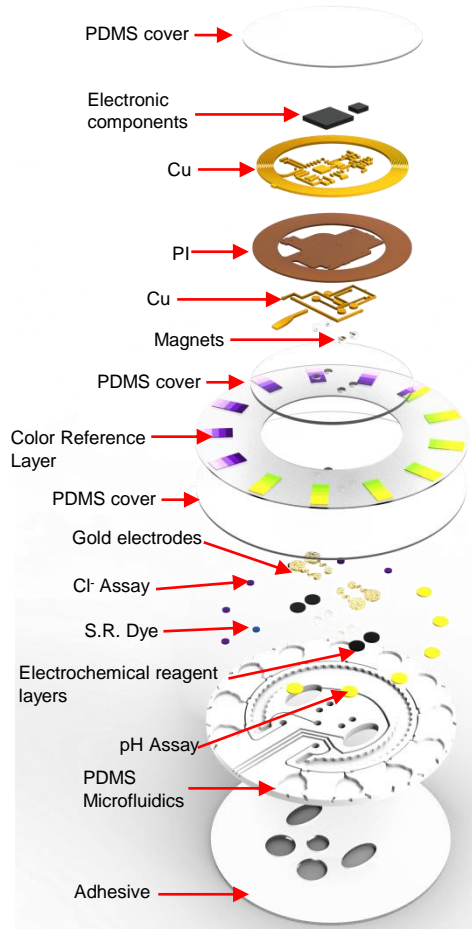


Image Analysis for Chloride, Zinc, and Sodium Levels



Sekine et al, Lab Chip, 2018

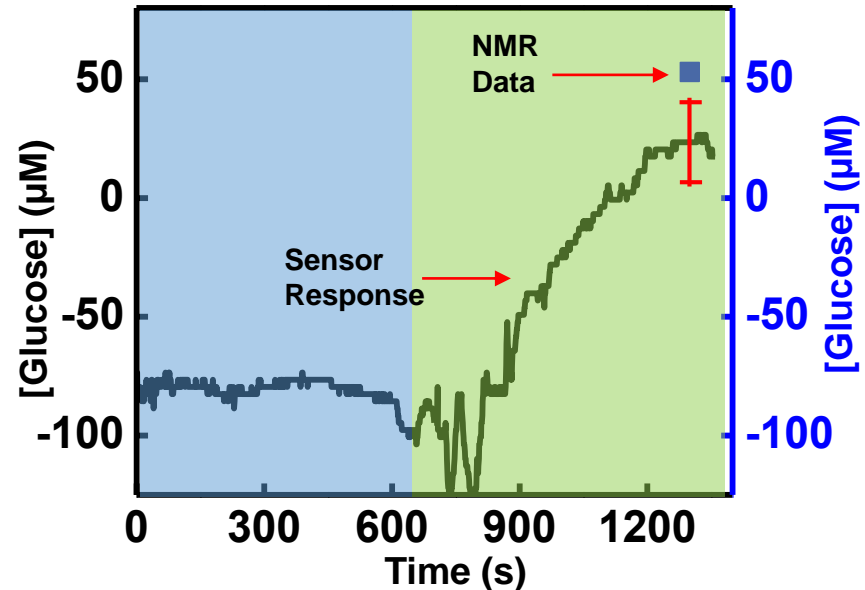
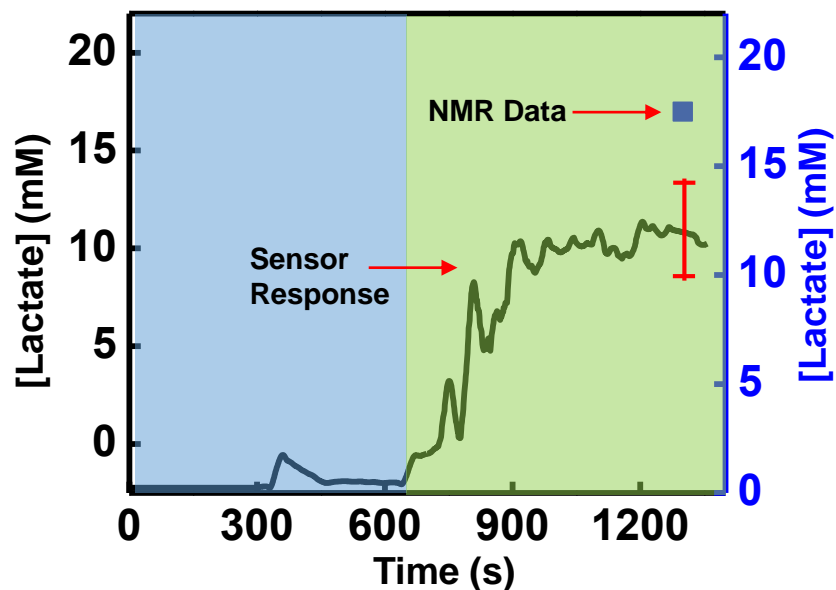
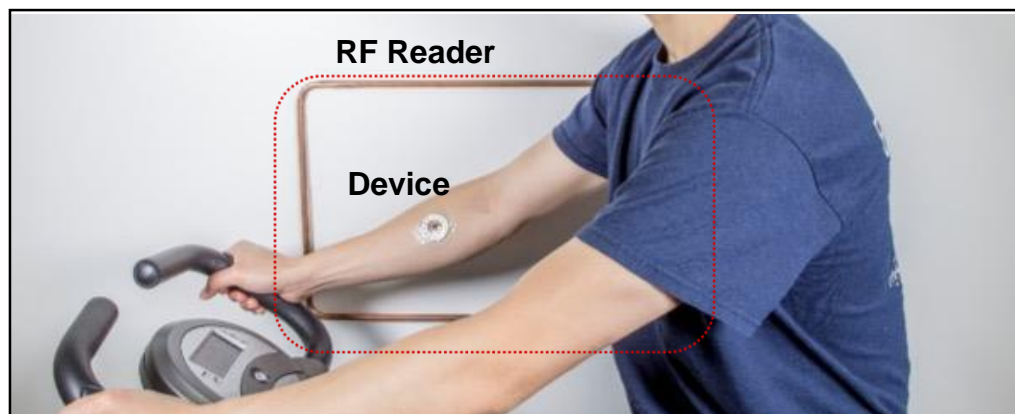
Electronics-Enabled Sweat Microfluidic Devices



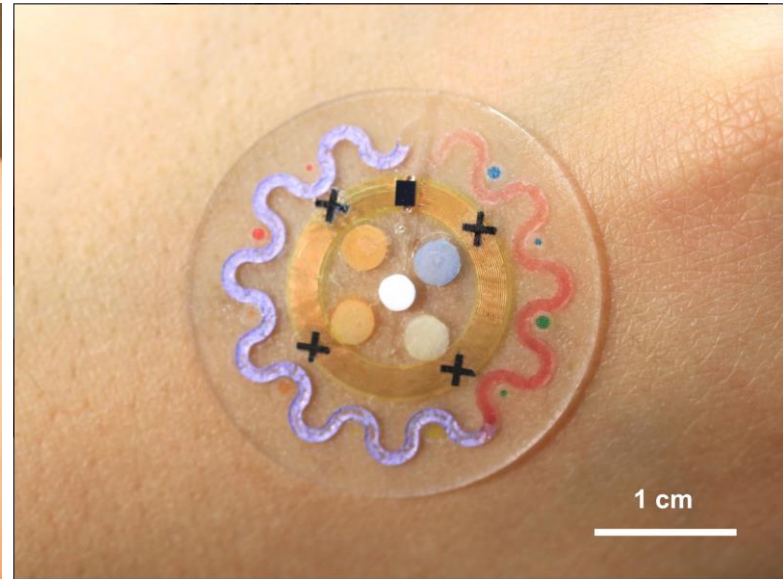
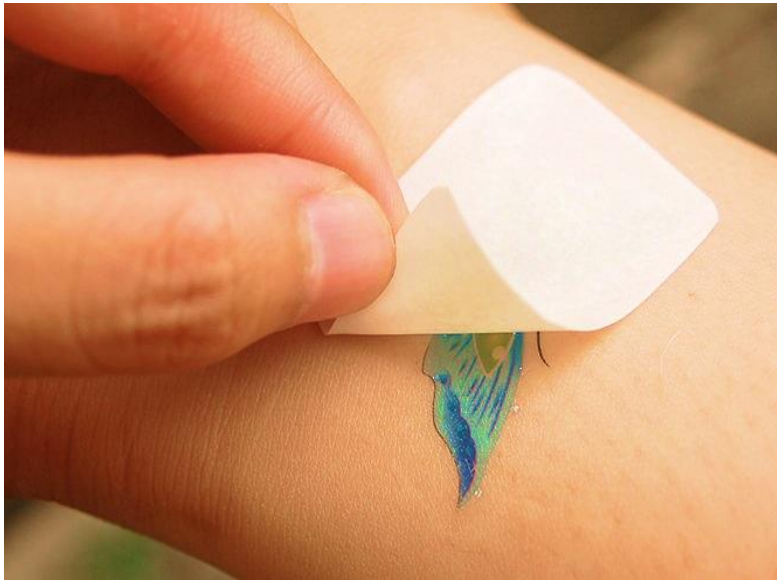
- Sweat rate
- Sweat biomarkers (sodium, glucose, lactate)
- Wireless communication

Bandodkar et al, in review

Battery Free, Real-Time Analysis of Sweat Biomarkers (Glucose, Lactate)



Tattoo-Like Functional Sweat Measurement Devices



- Mechanically invisible
- Light-weight and unobtrusive
- Tight coupling with skin



- Portable monitoring
- Multiple modalities
- Enhanced signal quality
- New sensing capabilities

Acknowledgements

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