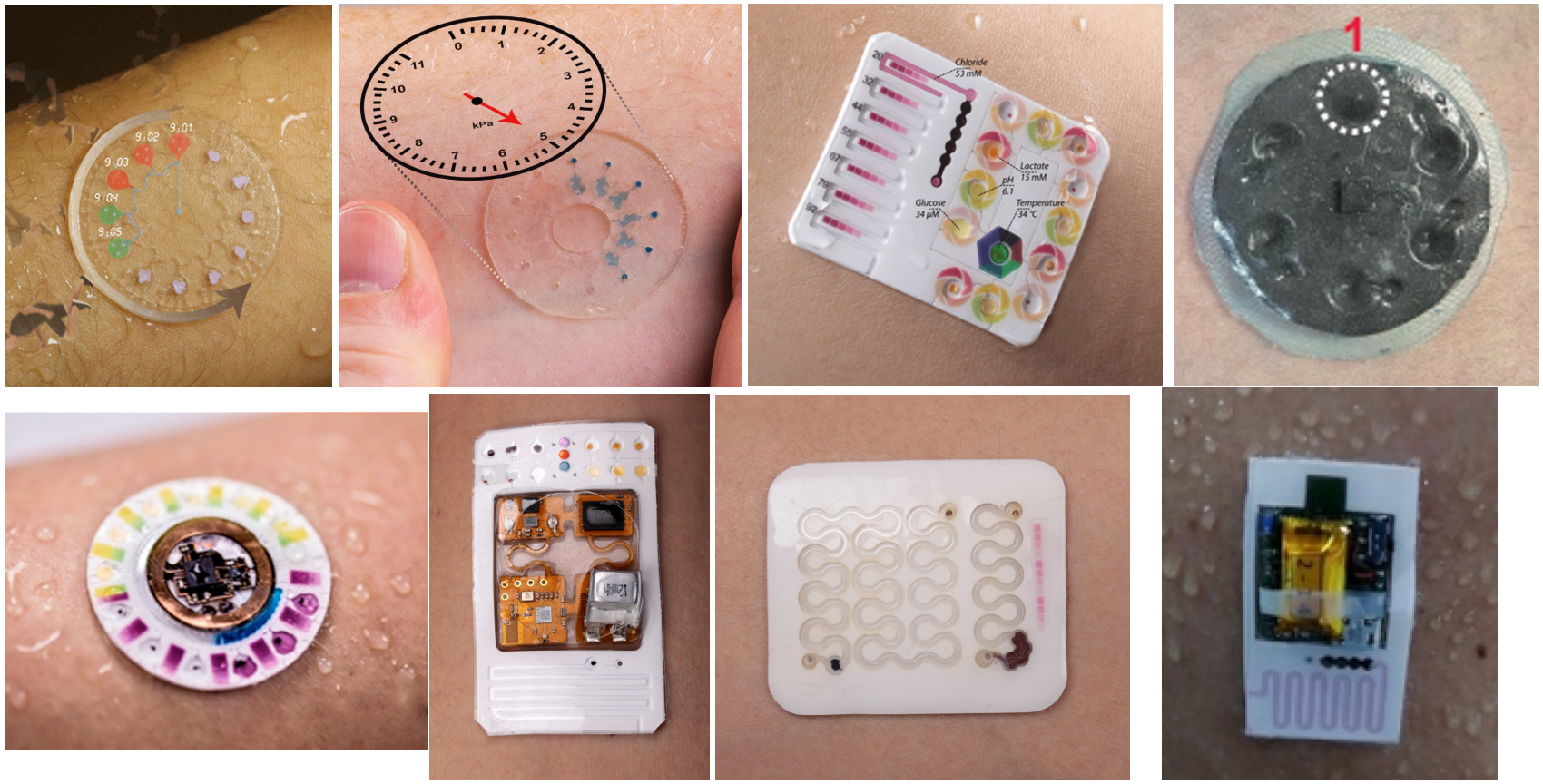
미세유체 기반 헬스케어 플랫폼



2025년 12월 18일

최정일
아주대학교

연사 소개

최 정 일

E-mail: cji@ajou.ac.kr

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Homepage: softlab.ajou.ac.kr

Education

B.S 2001-2007 Seoul National Univ. **Mechanical** and Aerospace Engineering

M.S 2008-2010 Seoul National Univ. **Mechanical** and Aerospace Engineering (터보기계연구실)

PhD 2011-2015 Seoul National Univ. **Electrical** and Computer Engineering

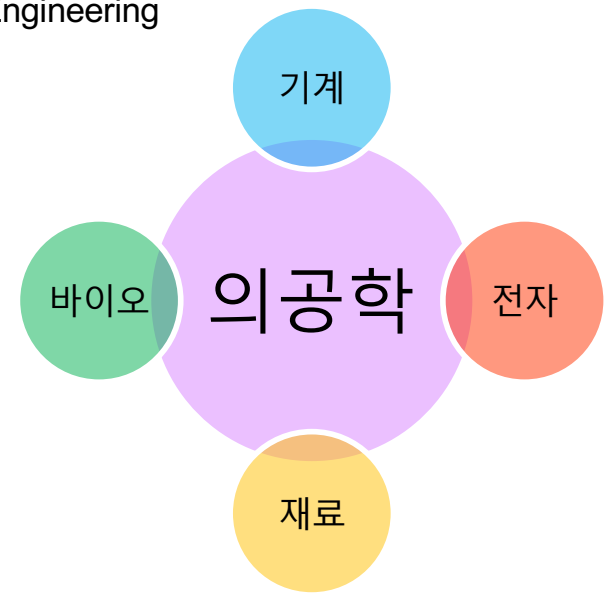
Career

2015-2016 **Quantamatrix**, Inc. (의공학 스타트업)

2016-2019 Northwestern Univ. **Material** Science Engineering

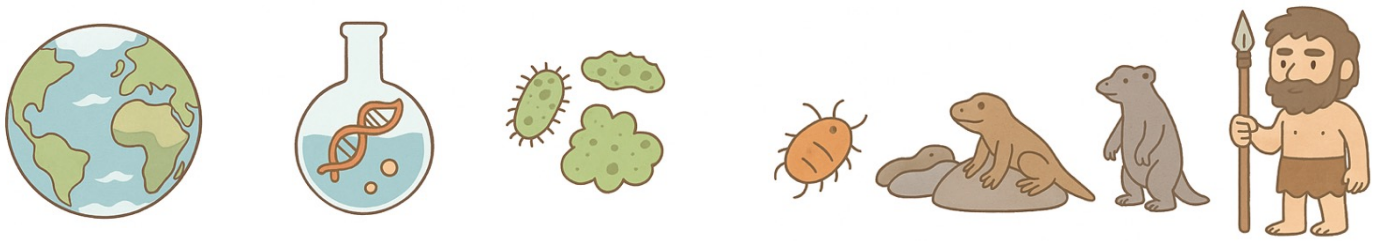
2019-2021 Kookmin Univ. School of Mechanical Engineering

2022- Ajou Univ. Dept. Mechanical Engineering



지구와 생명의 역사

- 지구의 생성: 46억 년 전
- 생명의 기원: 약 40억 년 전, 유기 분자 (유전 물질)
  - **해양**에서 화학 반응이 일어나 생명의 조직인 세포가 형성 '추정'
- 35억 년 전 : 조류와 미생물 등의 간단한 생물체
- 20억 년 전 : 광합성 시작→ 산소가 대기로 노출
- 5억 년 전 : 다세포 생물(곤충, 양서류, 파충류, 포유류 등의 진화)
- 600만년 전 : 인간의 공통 조상 등장
- 20만년 전 : *homo sapiens* 등장
- 1만년 전 : 문명의 발전



바이오유체와 세포의 크기

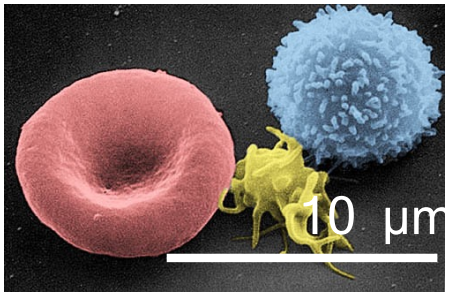
Biofluids

Blood
Sweat
Saliva
Urine

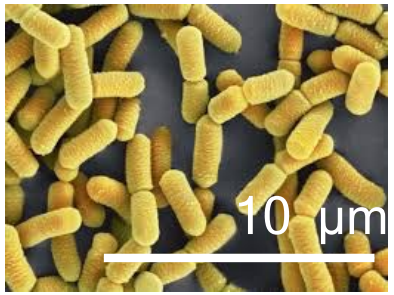
shoalhavenspringwater.com

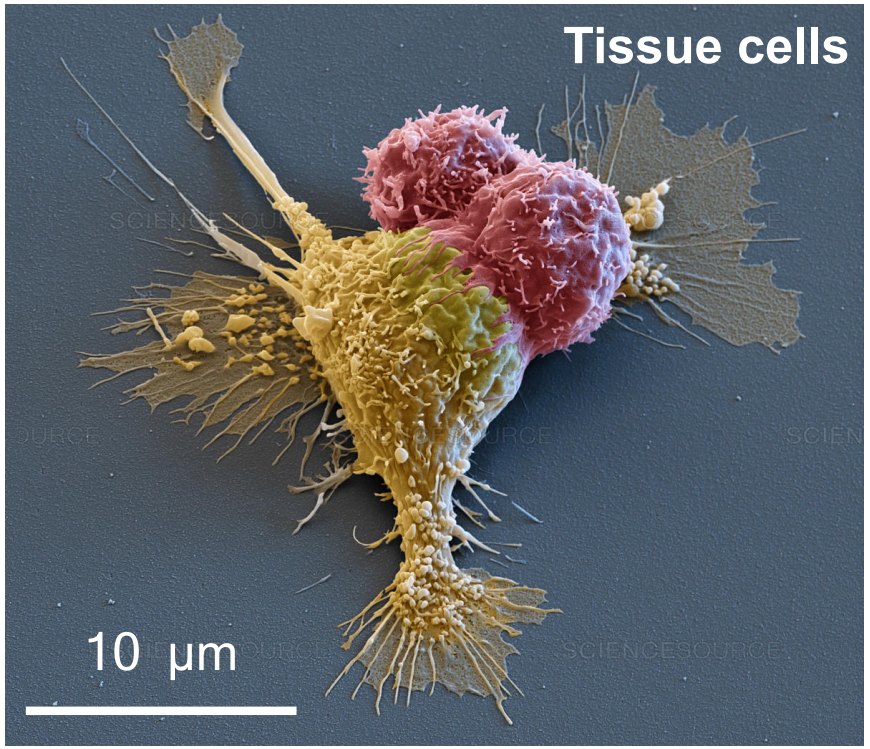
Micron-sized Cells

Blood cells



Bacteria cells





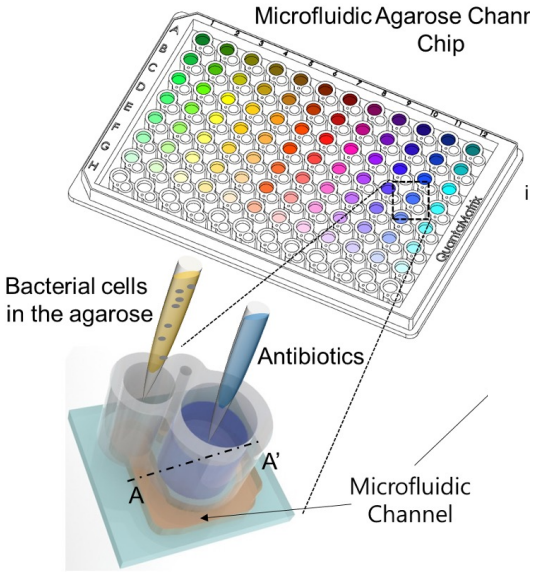
wordpress.com, sciencesource.com

바이오유체 관련 연구 주제

웨어러블 땀센서

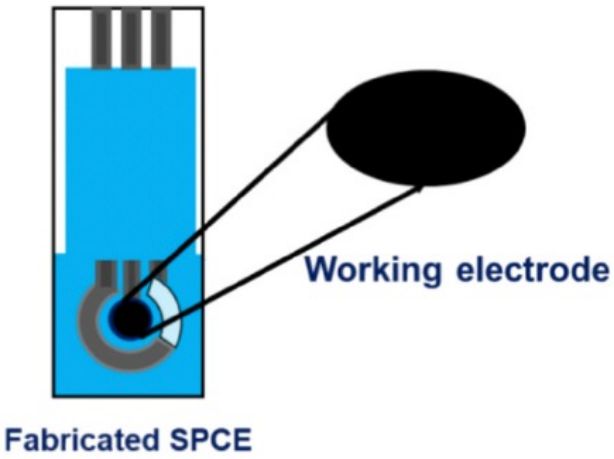
Lab Chip, 2025
Chem. Eng. J., 2025
Adv. Health. Mat.,2021
Adv. Func. Mat.,2021
Sci. Adv., 2019
Sci. Adv., 2018

세포 약물 검사



Lab Chip, 2025
Lab Chip, 2023
Lab Chip, 2020
Sci. Trans. Med., 2015

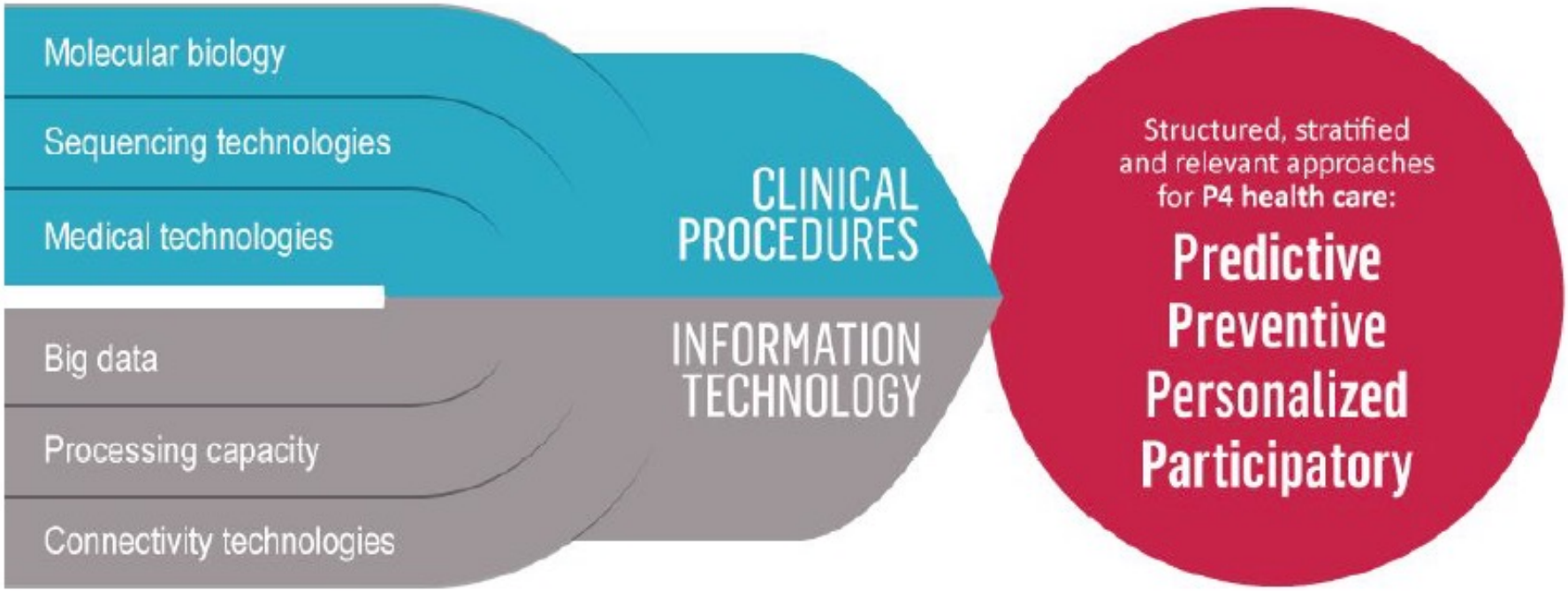
진단 센서



Bioelectrochemistry, 2025
ACS Sens., 2023
Anal. Chim. Acta, 2023

4P-centric medical practice

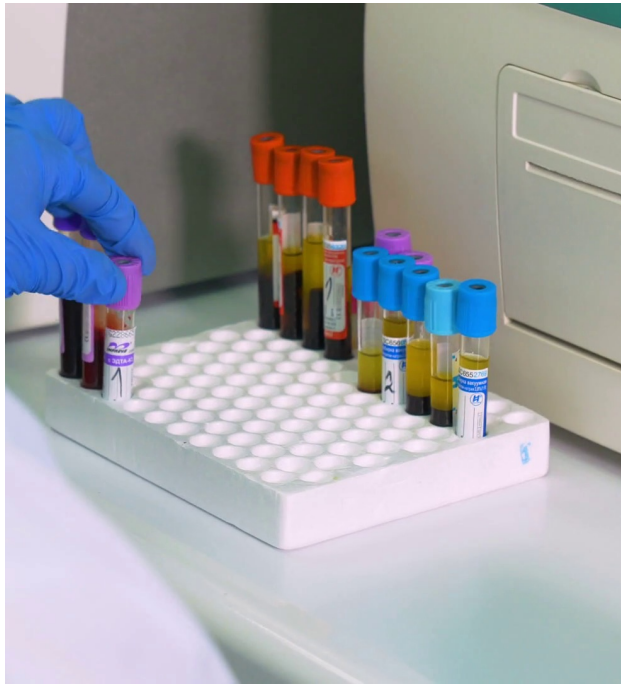
- Paradigm shift in medical practice
- Treatment → Disease Prevention and Health Care



* 출처: Quebec Network for Personalized Health Care (QNPHC)

From Lab Analysis to Wearable Sensors

Lab Analysis

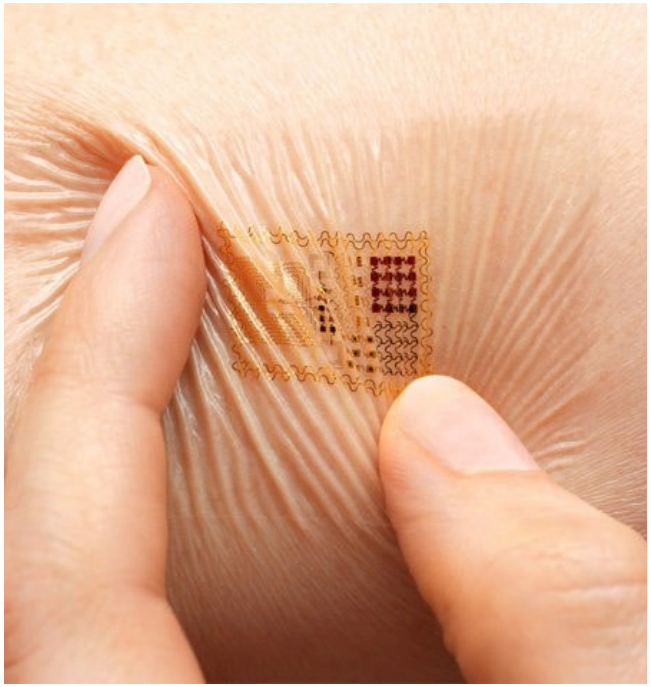


videoblocks.com

Point of Care

toptenselect.com

Wearable Sensors



Kim et al. Science (2011)

Sweat Analytics for Health Monitoring

Current: Blood

© Ilya Andriyanov / Shutterstock

New: Sweat

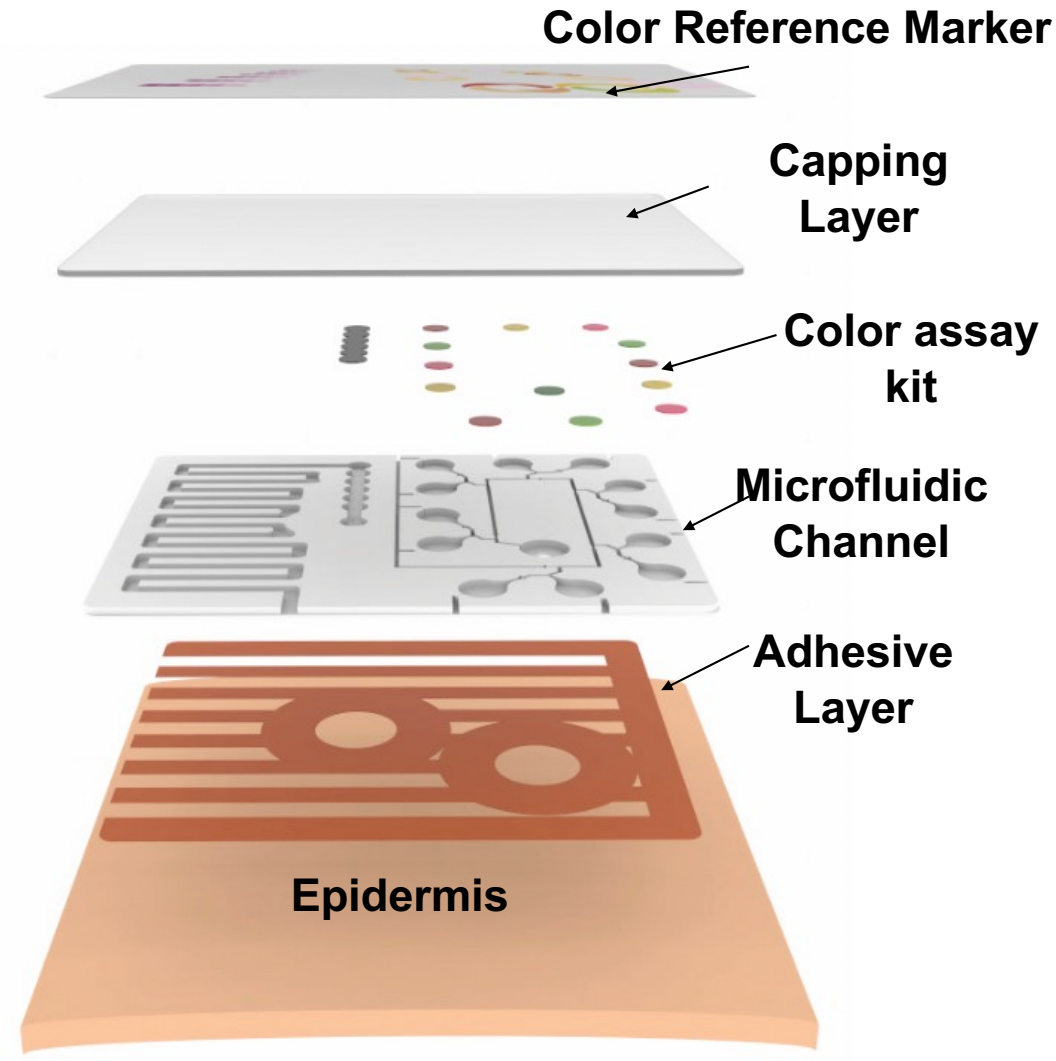
Rich content of important biomarkers

Biomarkers	*Physiological States*
Sweat rate	Dehydration
pH	Metabolic alkalosis
Glucose	Diabetes
Lactic acid	Physical exertion
Chloride ion	Electrolyte balance, Cystic fibrosis

Blood + Needle

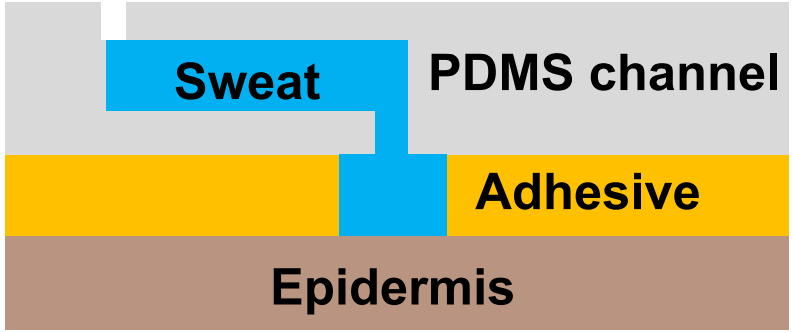
Sweat + Patch (non-invasive)

Soft, Colorimetric and Microfluidic Device



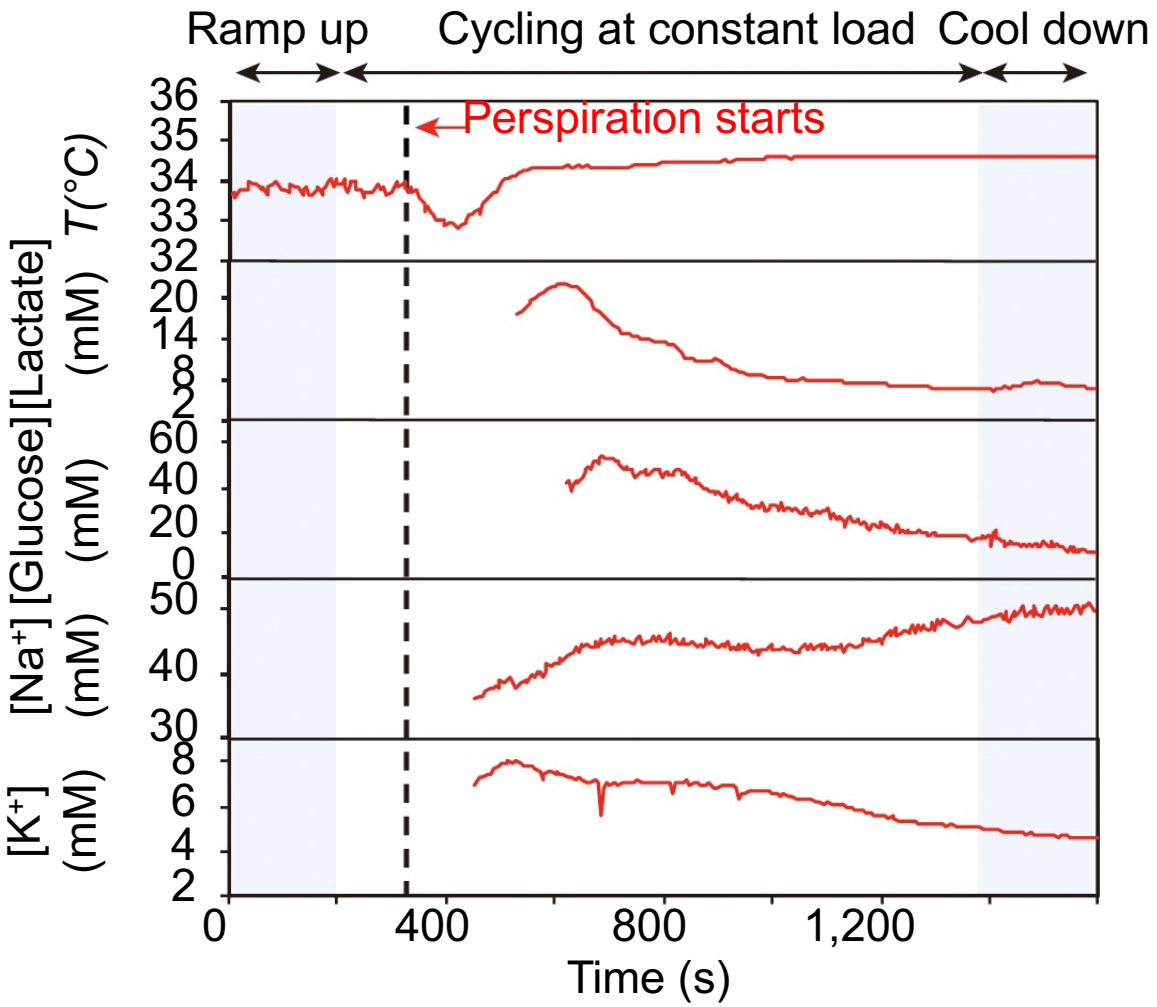
-Soft Mechanics (~1 MPa)
-Simple Colorimetric
-Chrono-Sampling
-Measuring Sweat Rate

Cross section view



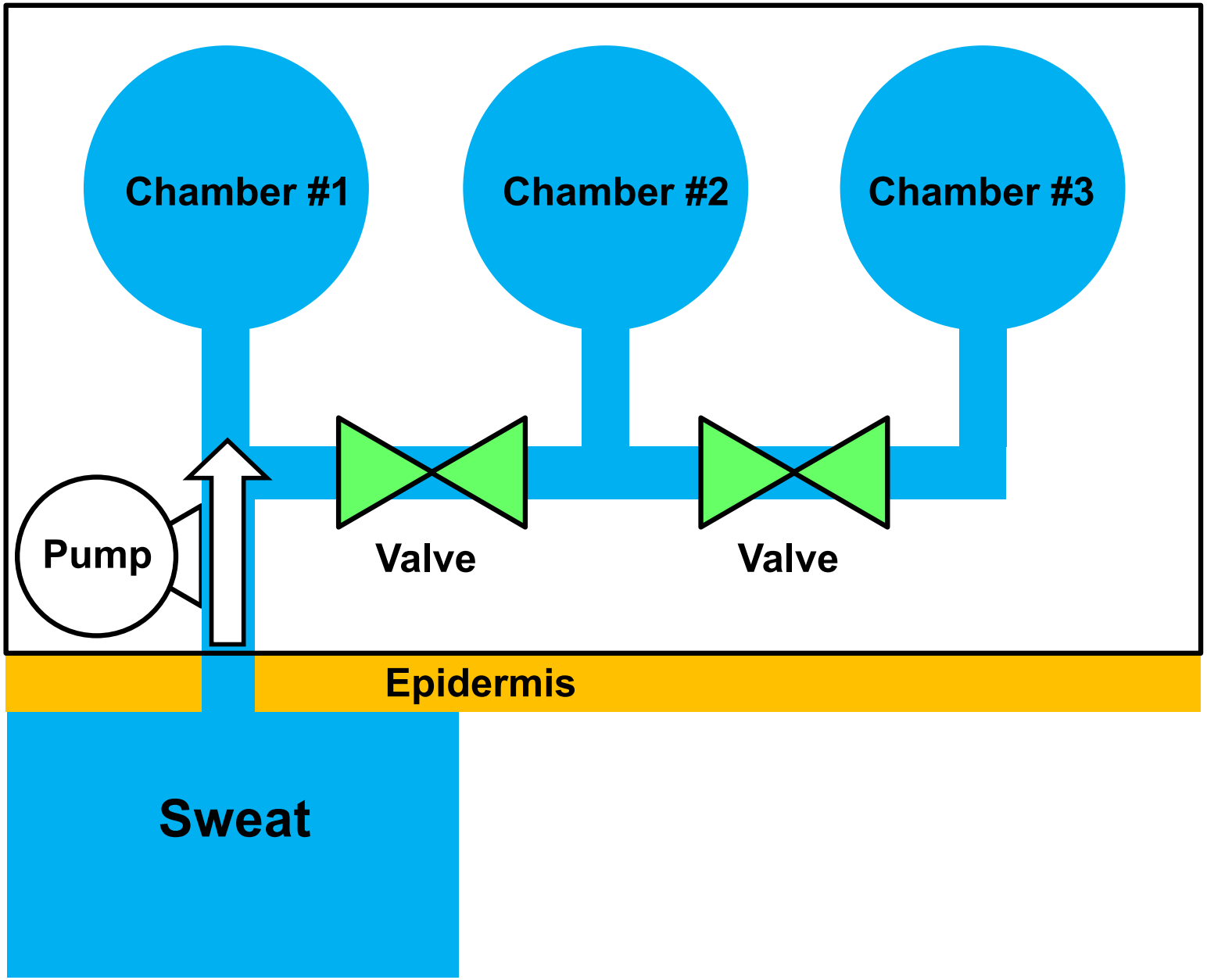
Sweat changes : Need of Chrono-sampling

AIR FORCE RESEARCH LABORATORY

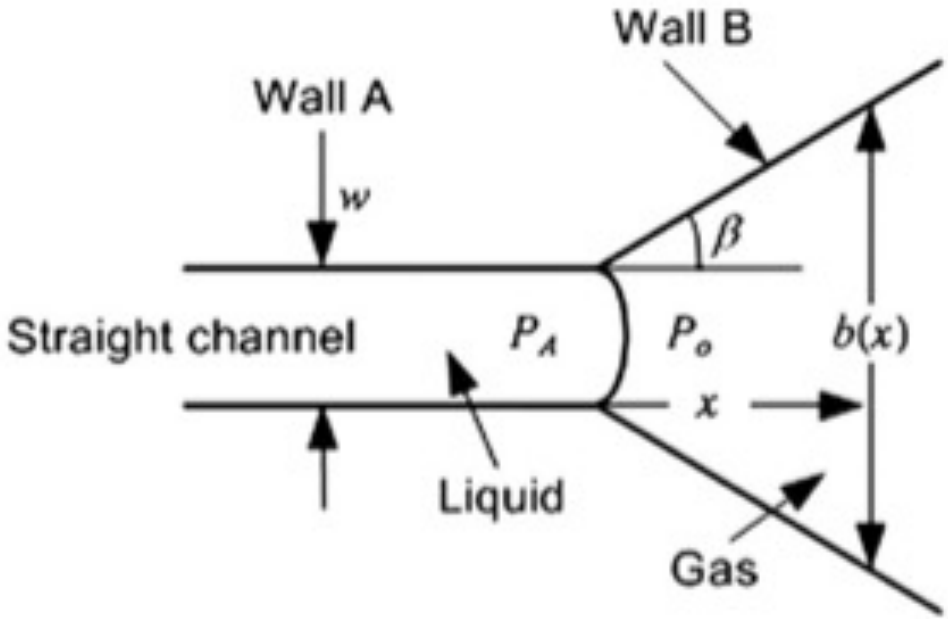


Gao et al., Nature (2016)

We need valves for chrono-sampling



Capillary bursting valve



contact angle: hydrophobicity

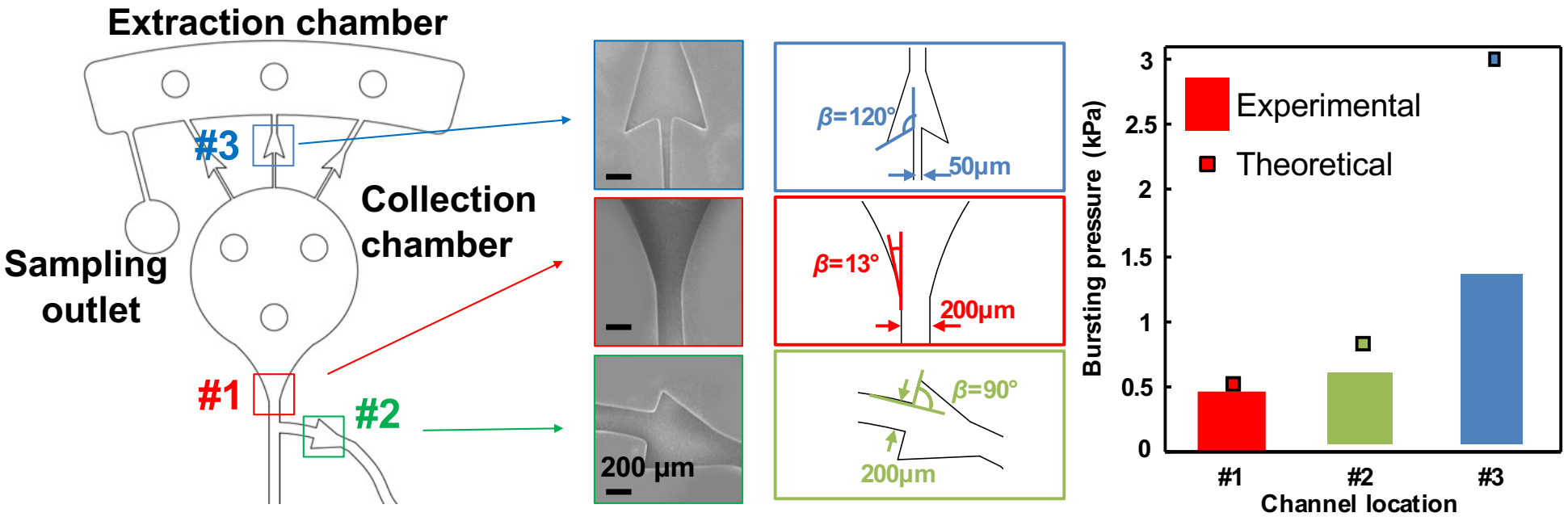
$$\textbf{Bursting Pressure} = -2\sigma\left(\frac{cos\theta_I^*}{w} + \frac{cos\theta_A}{h}\right)$$

Channel dimension

σ : surface tension of liquid
θ_A: contact angle of the channel
θ_I^* : min[θ_A+ β; 180°]
β : diverging angle of the channel
w : width of the diverging section
h : height of the diverging section

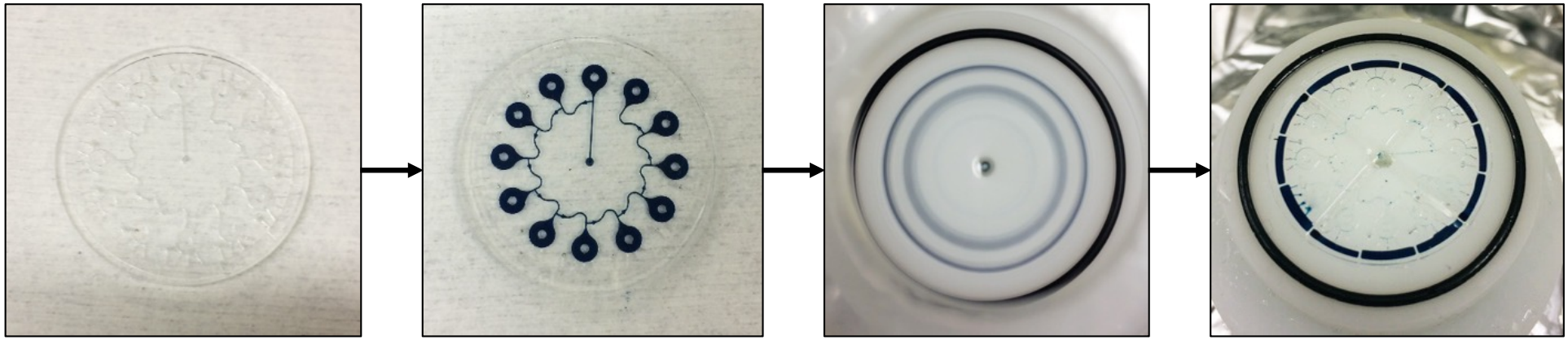
H. Cho et al., J. Colloid Interface Sci., 2007

Capillary Bursting Valves for Guiding Sweat



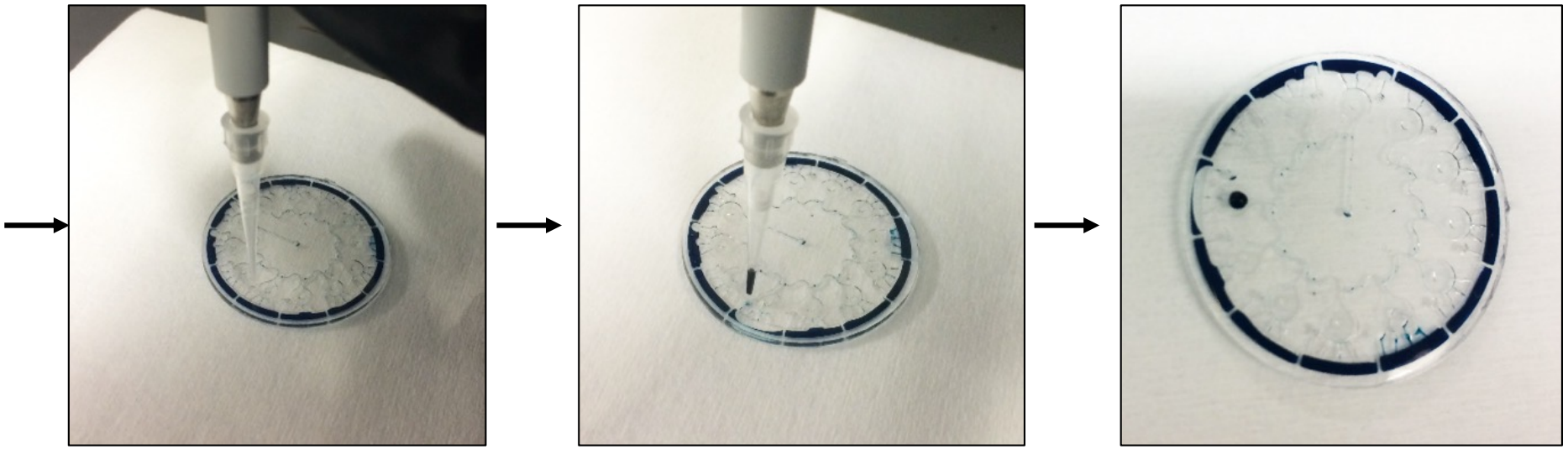
Choi et al., *Advanced Healthcare Materials* (2017)

Extraction Process for Laboratory Analysis



Sweat collection

Centurifugation

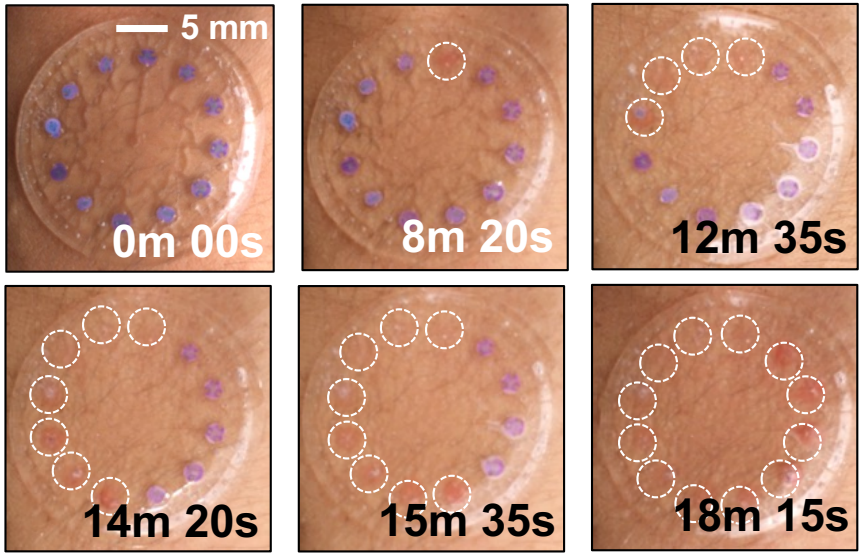


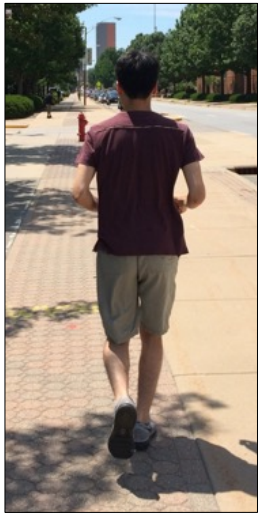
Recovery by pipetting

Recovered sweat

Choi et al., *Advanced Healthcare Materials* (2017)

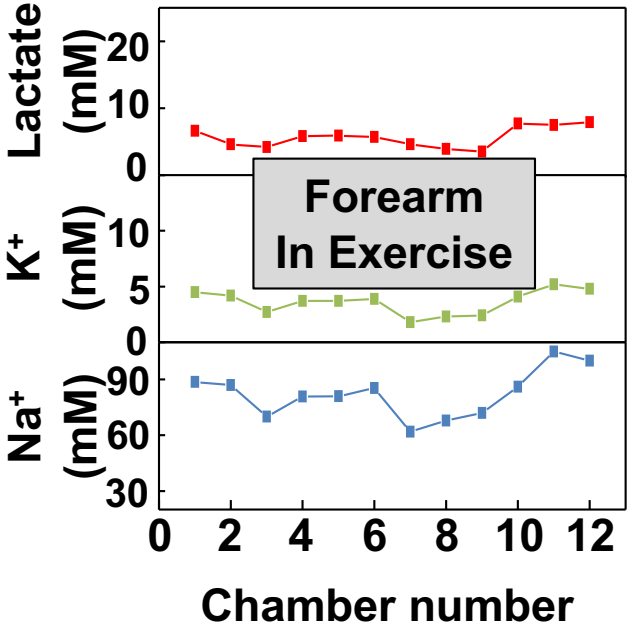
Temporal and Spatial Chemical Analysis

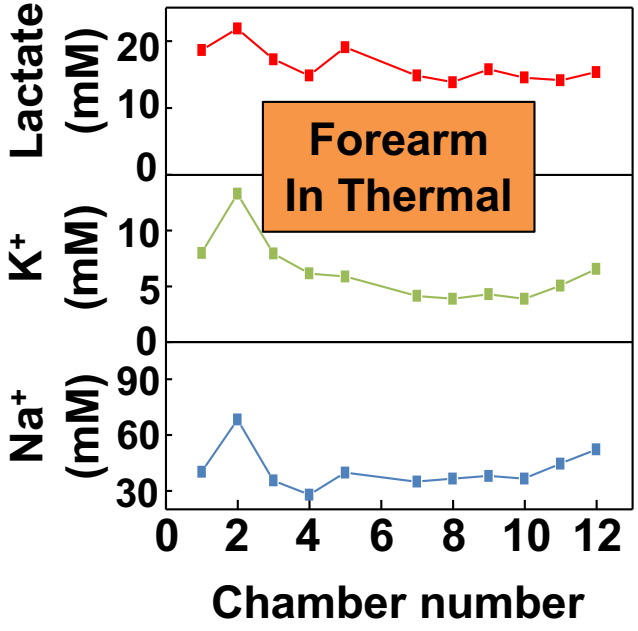


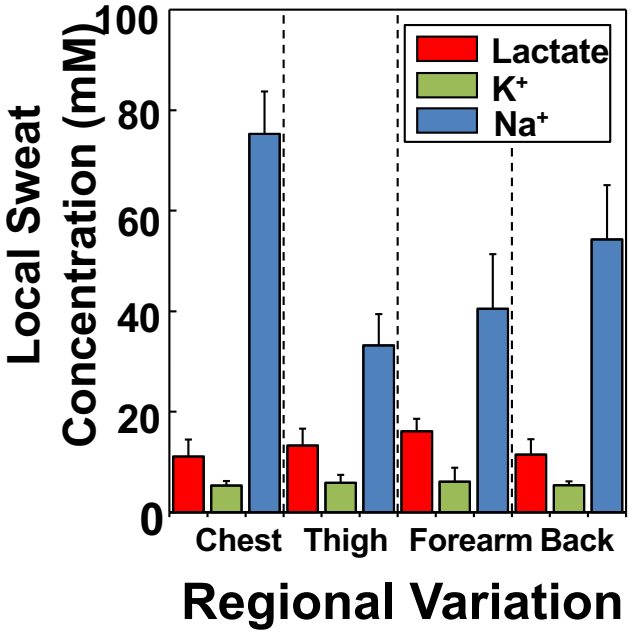


Exercise

Thermal Exposure

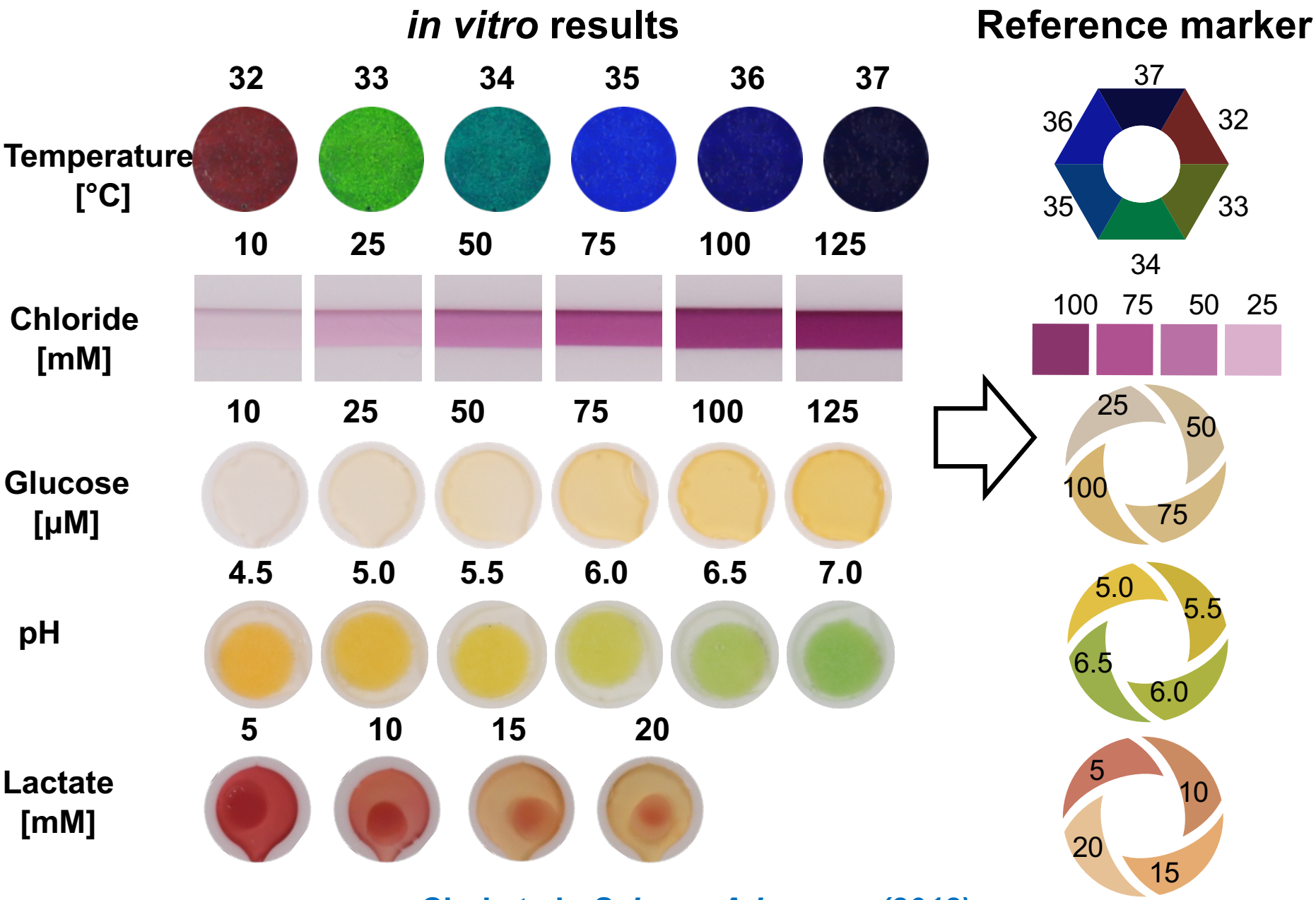






Choi et al., *Advanced Healthcare Materials* (2017)

Colorimetric Assays



Choi et al., *Science Advances (2018)*

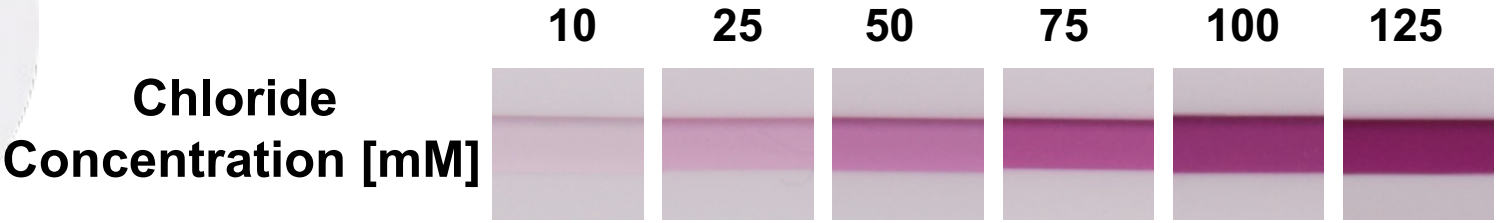
Colorimetric Chloride Detection

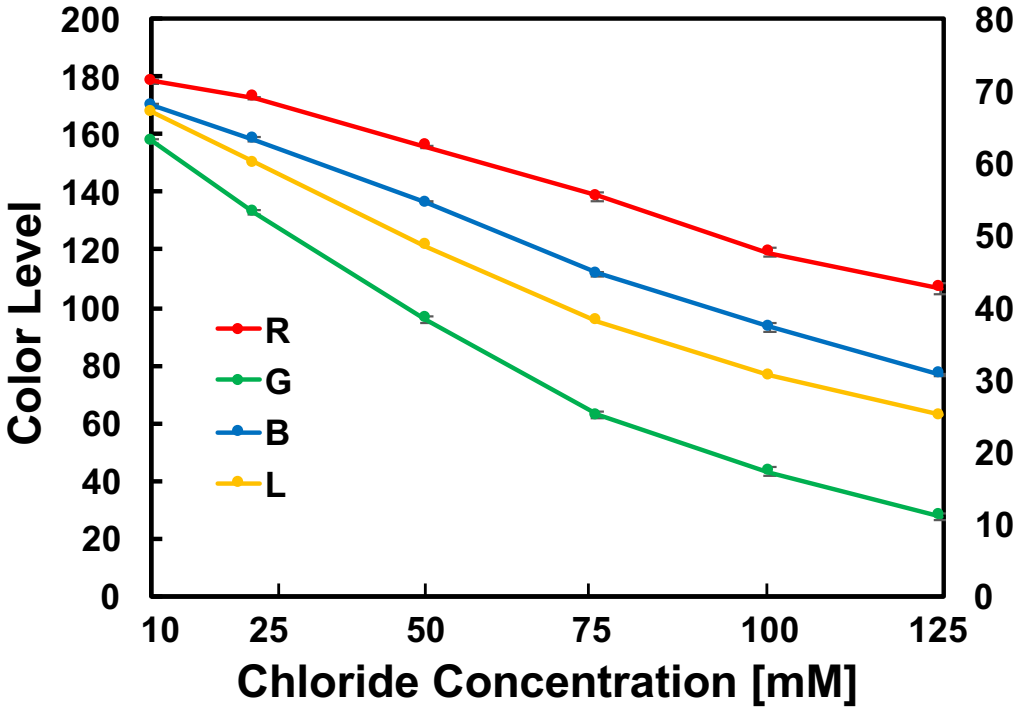
Chloride Assay

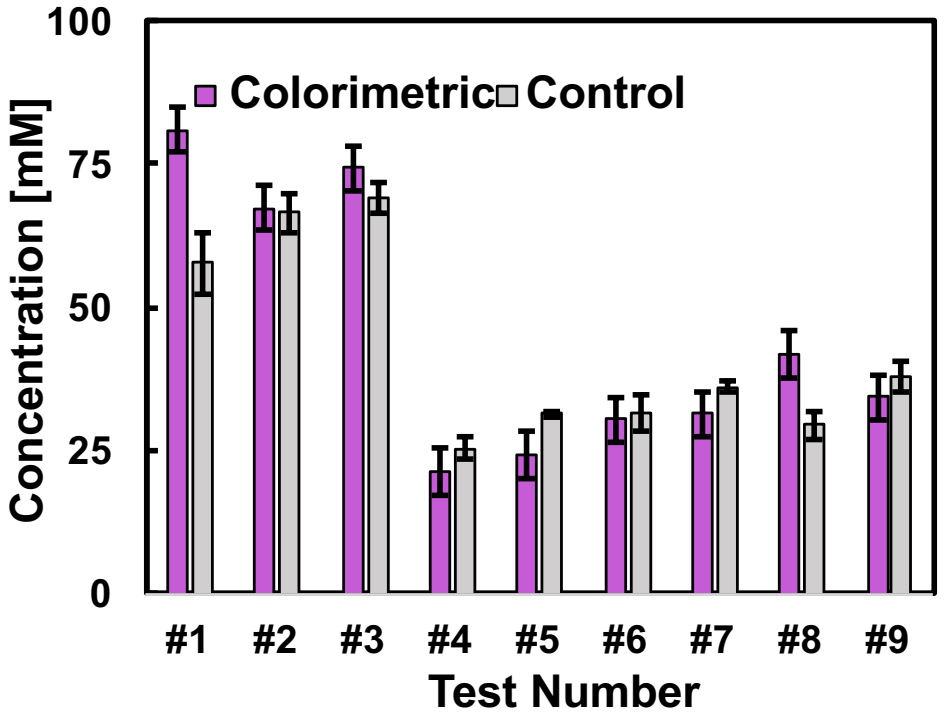
Chloride in sweat

$$C_6Ag_2Cl_2O_4 + 4Cl^- + H^+ \rightarrow 2AgCl_2(s) + HC_6Cl_2O_4^- \text{ (purple ion)}$$

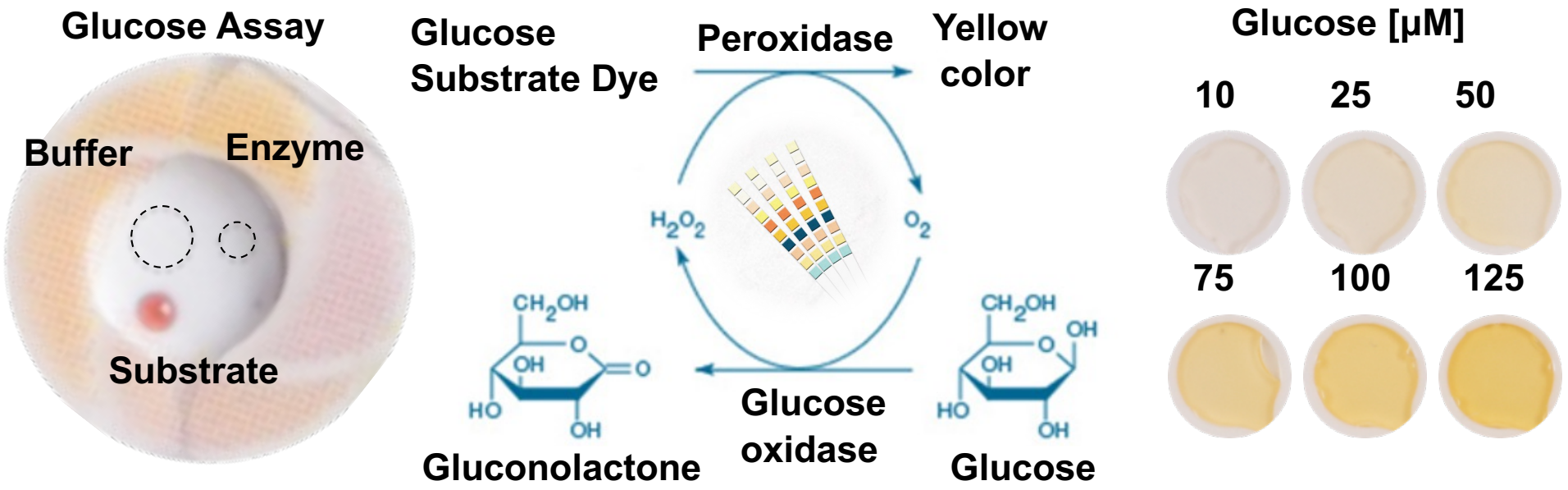
Silver Chloranilate — precipitation — Acid chloranilate ion

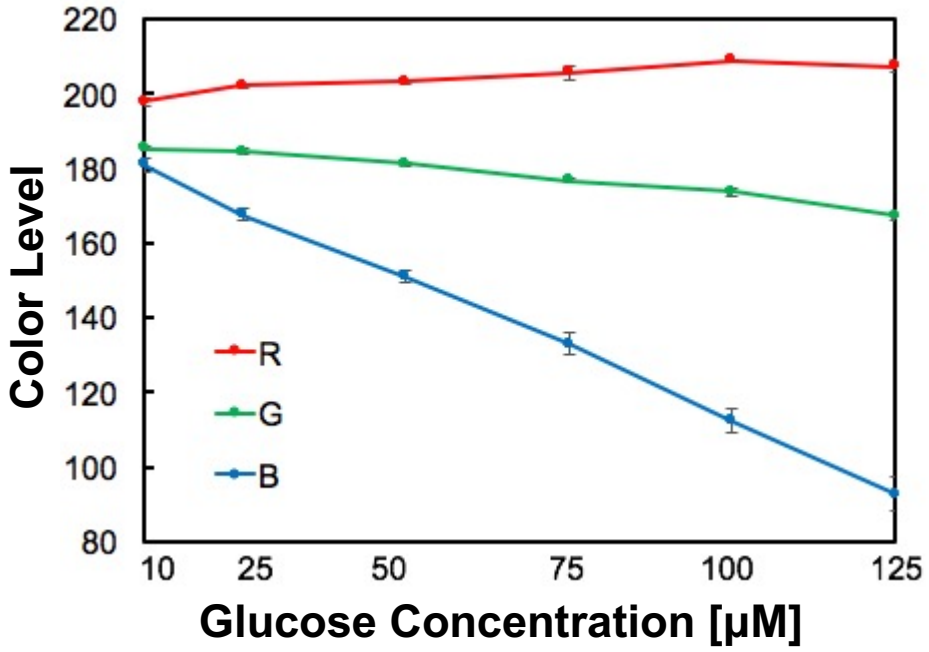


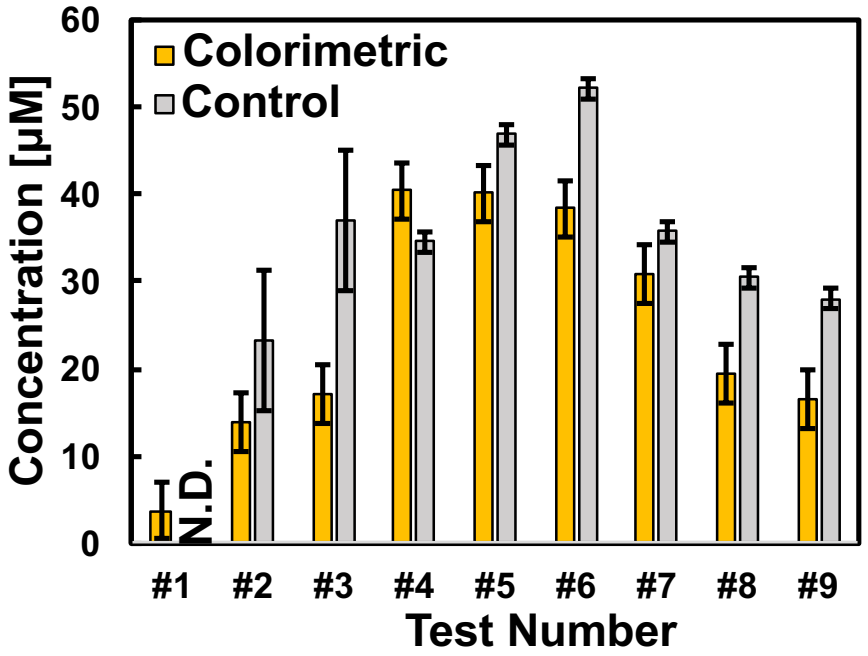




Colorimetric Glucose Detection







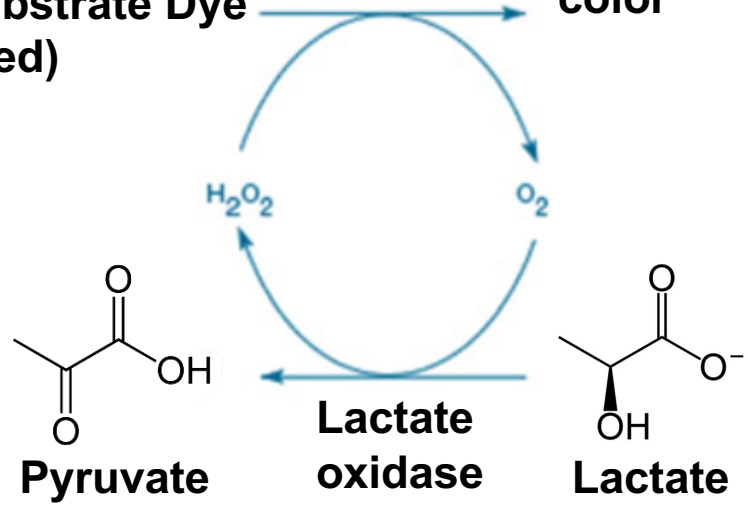
Colorimetric Lactate Detection

Lactate Assay Mixture

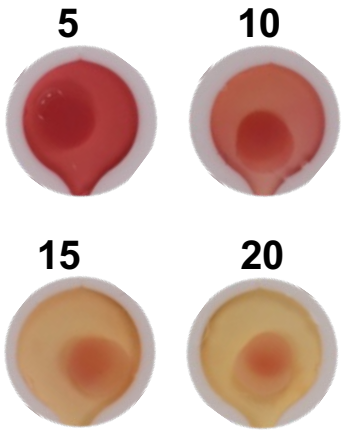
Lactate Substrate Dye (Red)

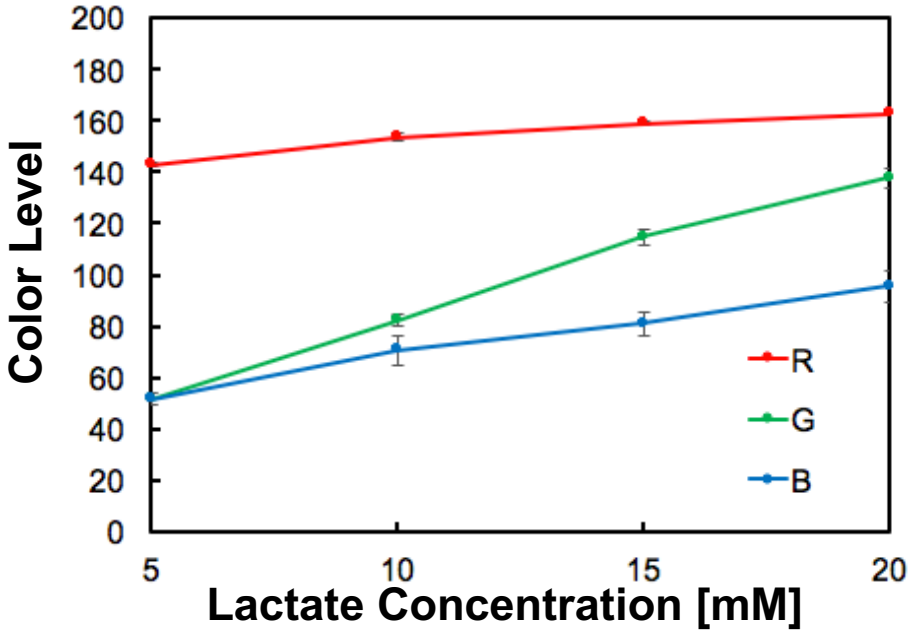
Peroxidase

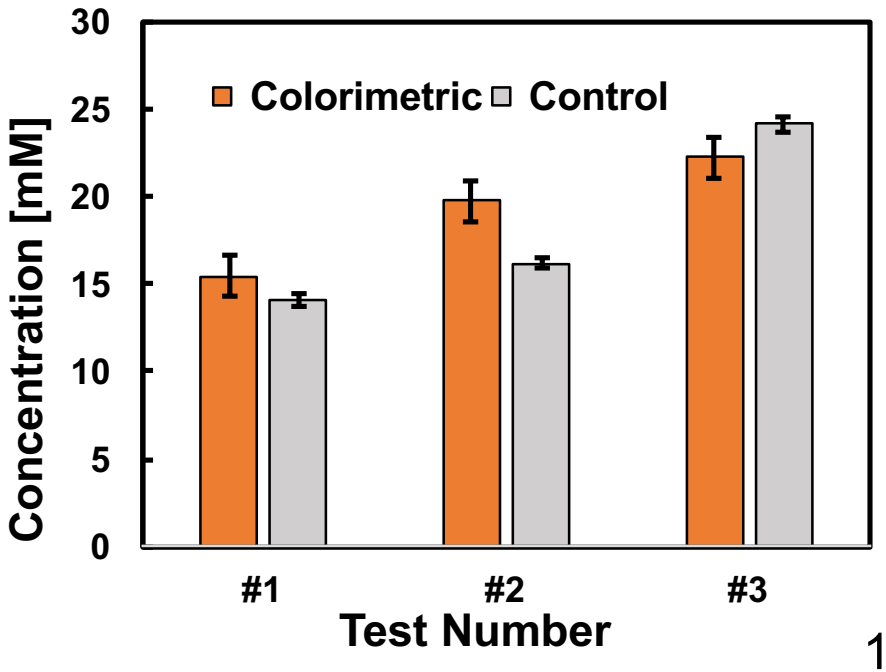
Yellow color



Lactate [mM]



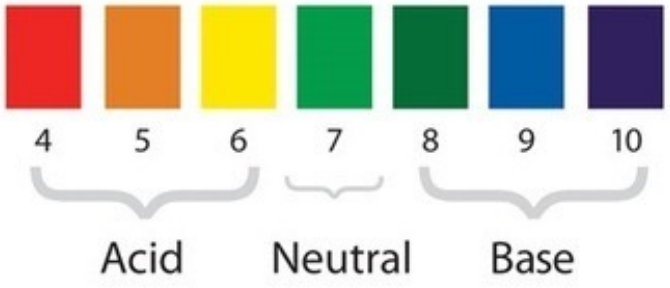




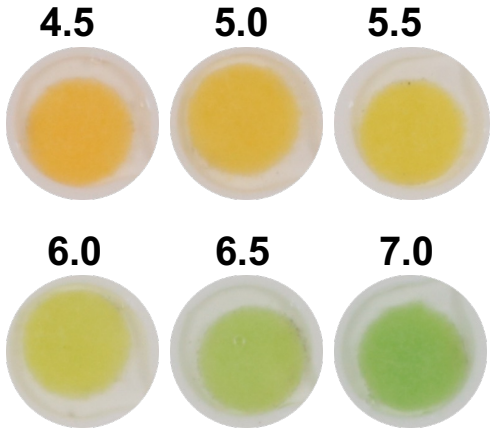
Colorimetric pH Detection

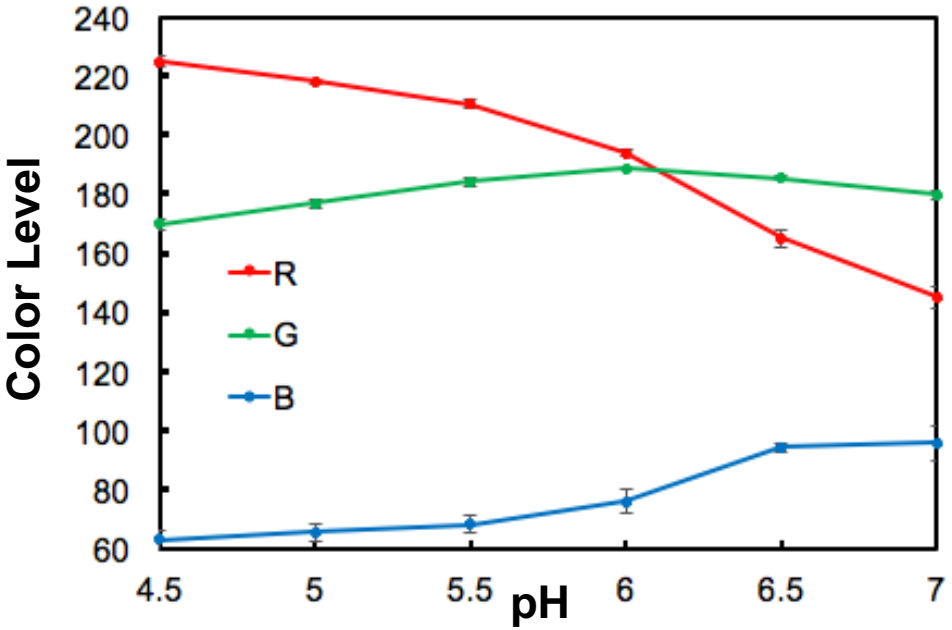
pH Assay Paper

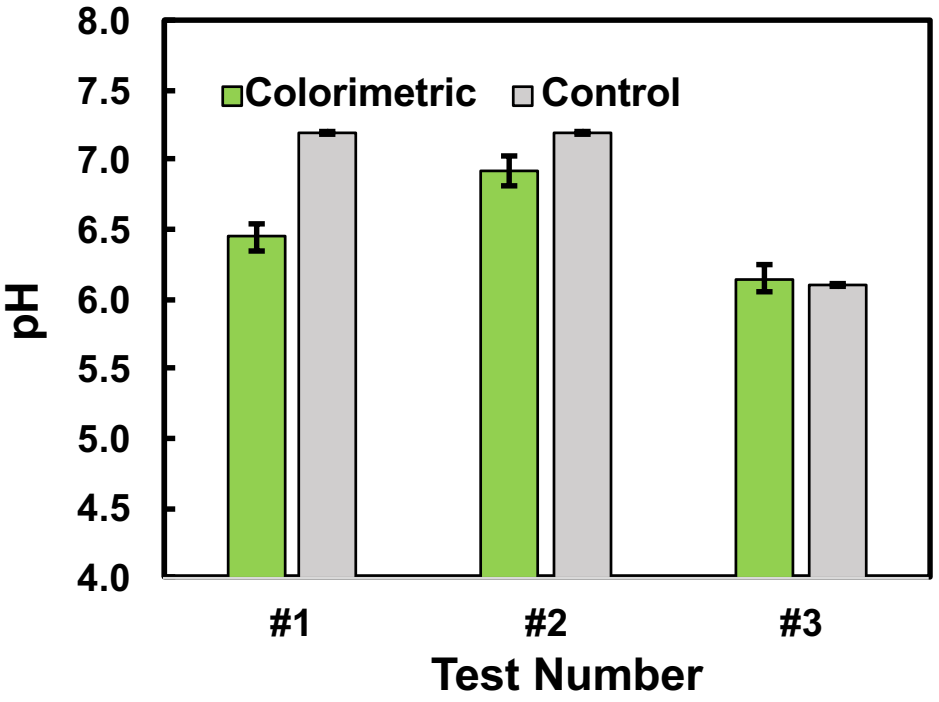
Universal Indicator pH



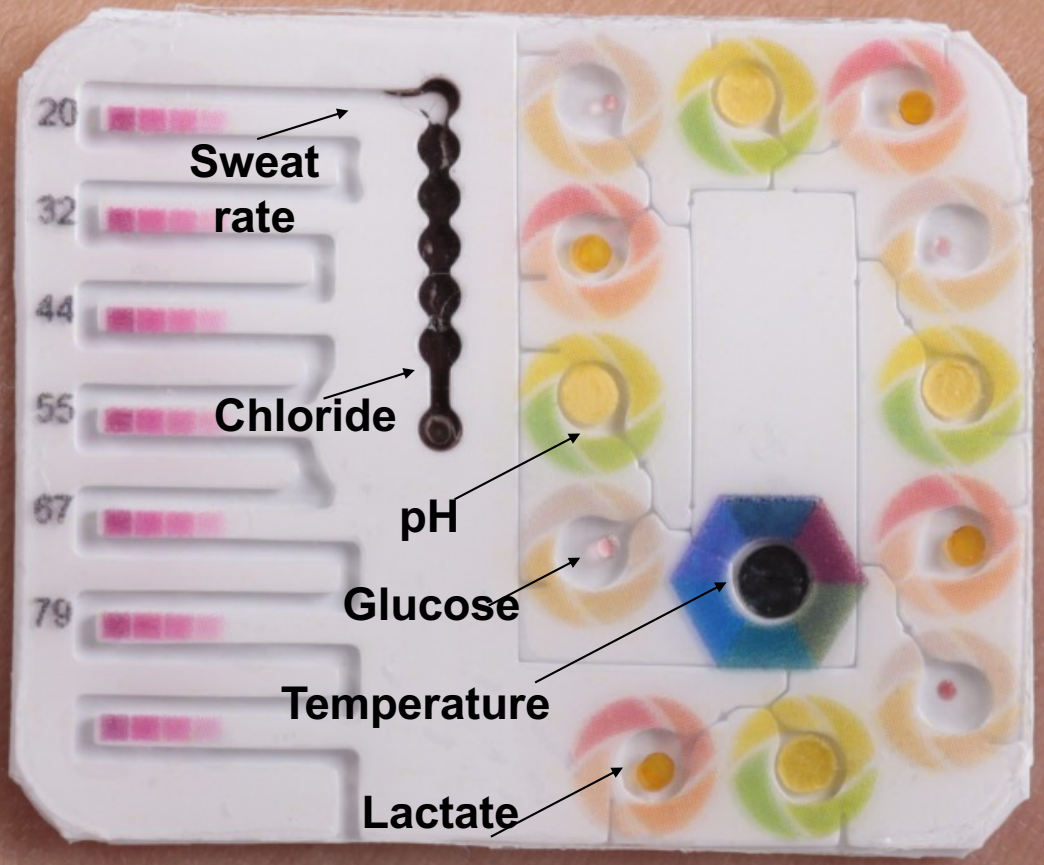
pH





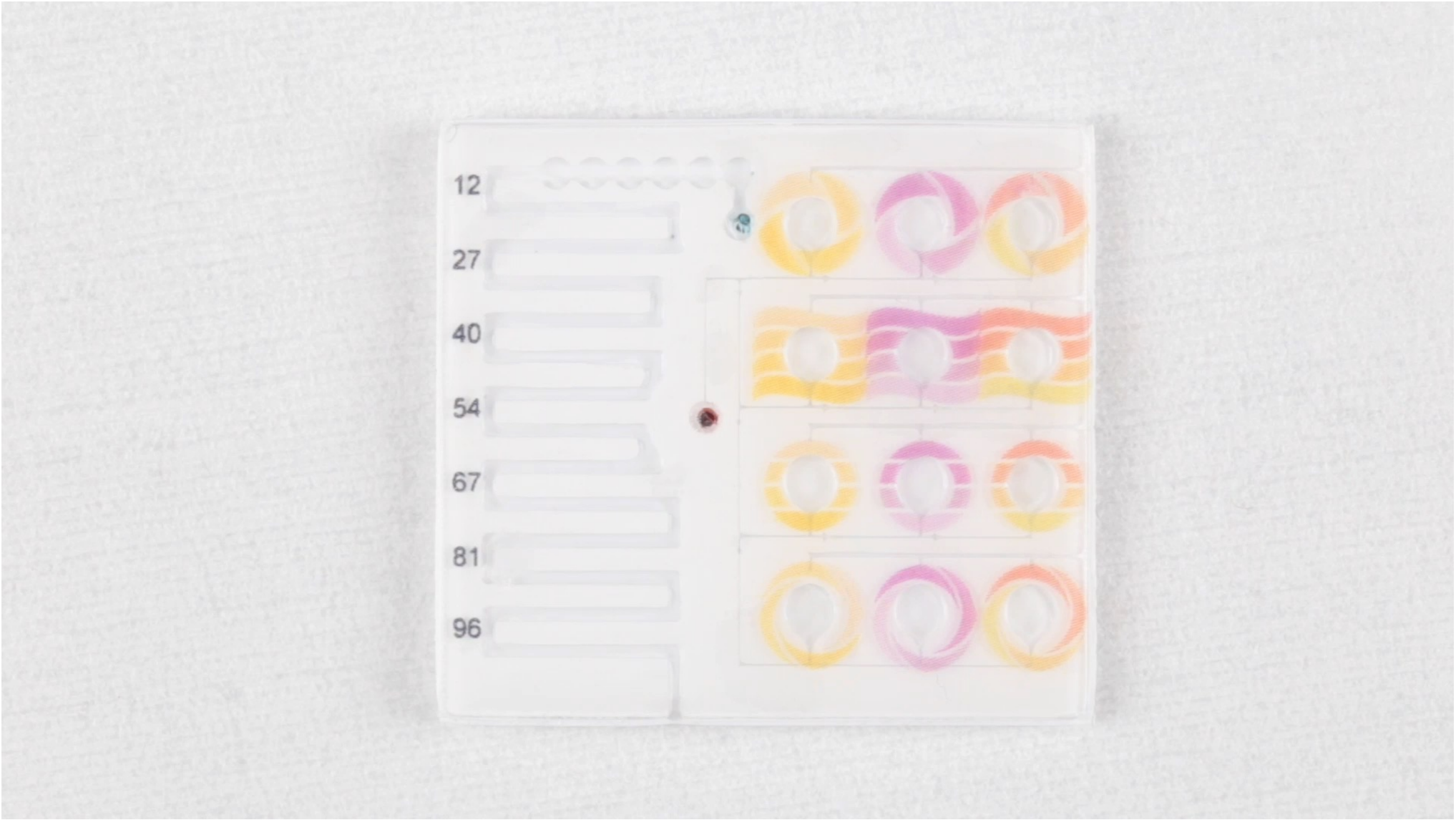


Microfluidic Colorimetric Sweat Device



-Soft
-Simple colorimetric
-Time Sequential
-No Needs calibration
-Sweat rate

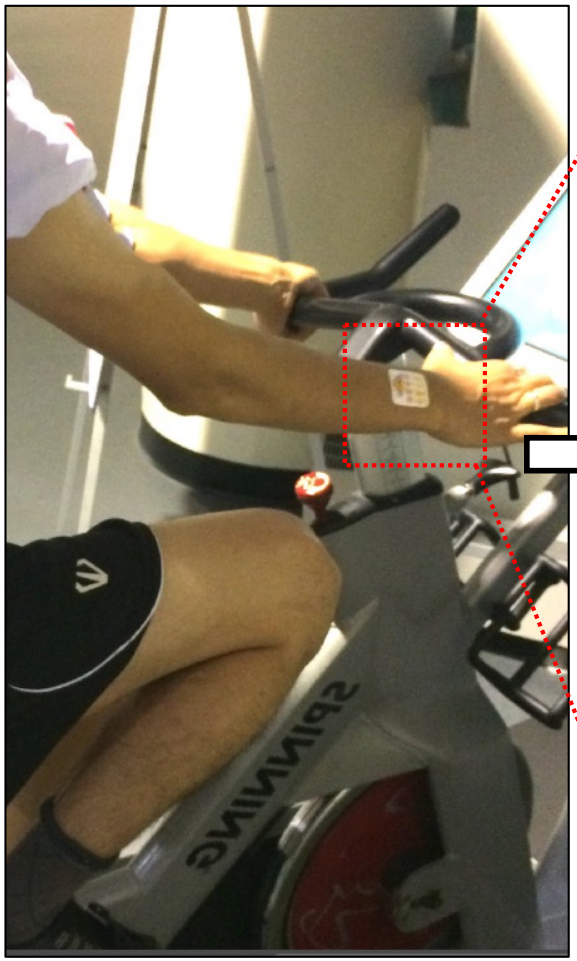
Chrono-sampling of sweat



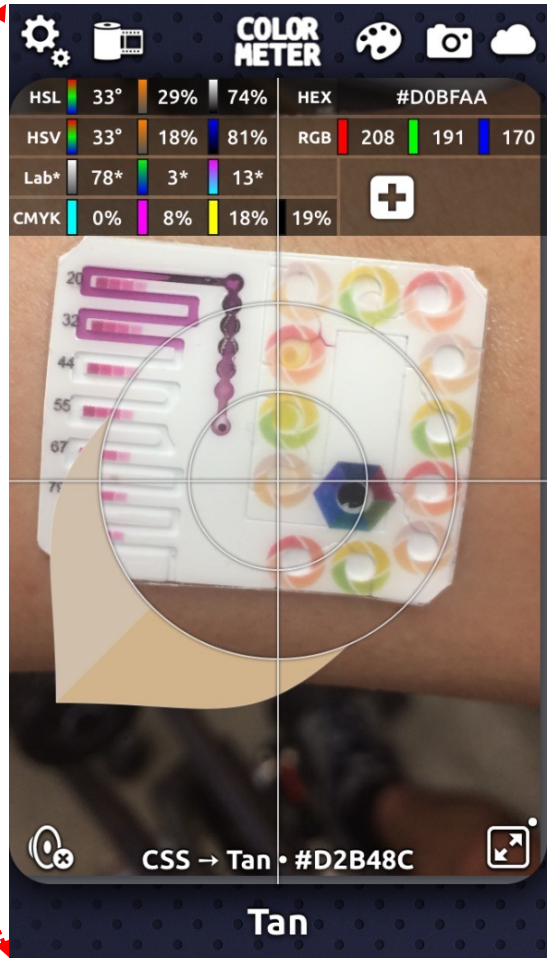
Choi et al., *Advanced Healthcare Materials* (2017)

In Situ Sweat Analysis

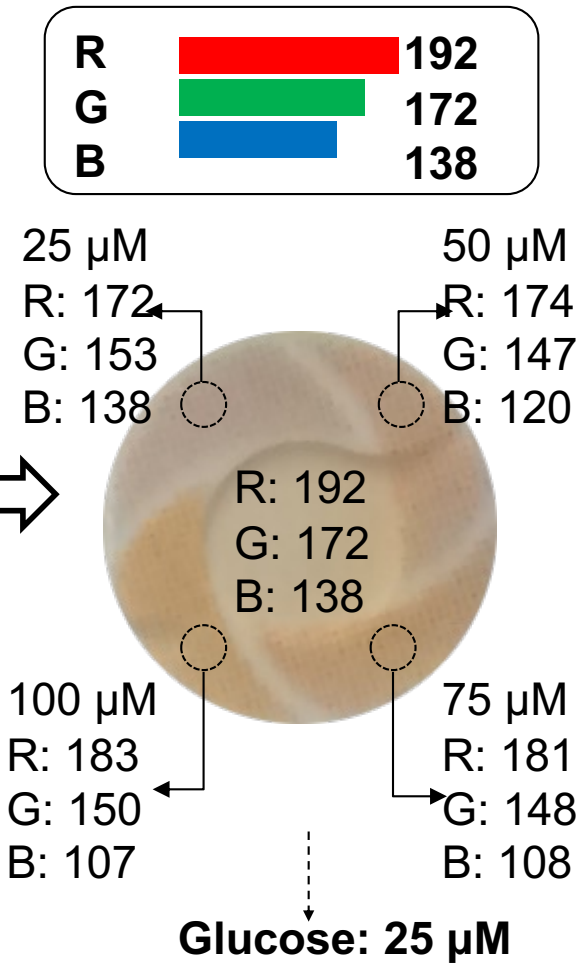
Exercising



Analyzing Color By Smartphone App.

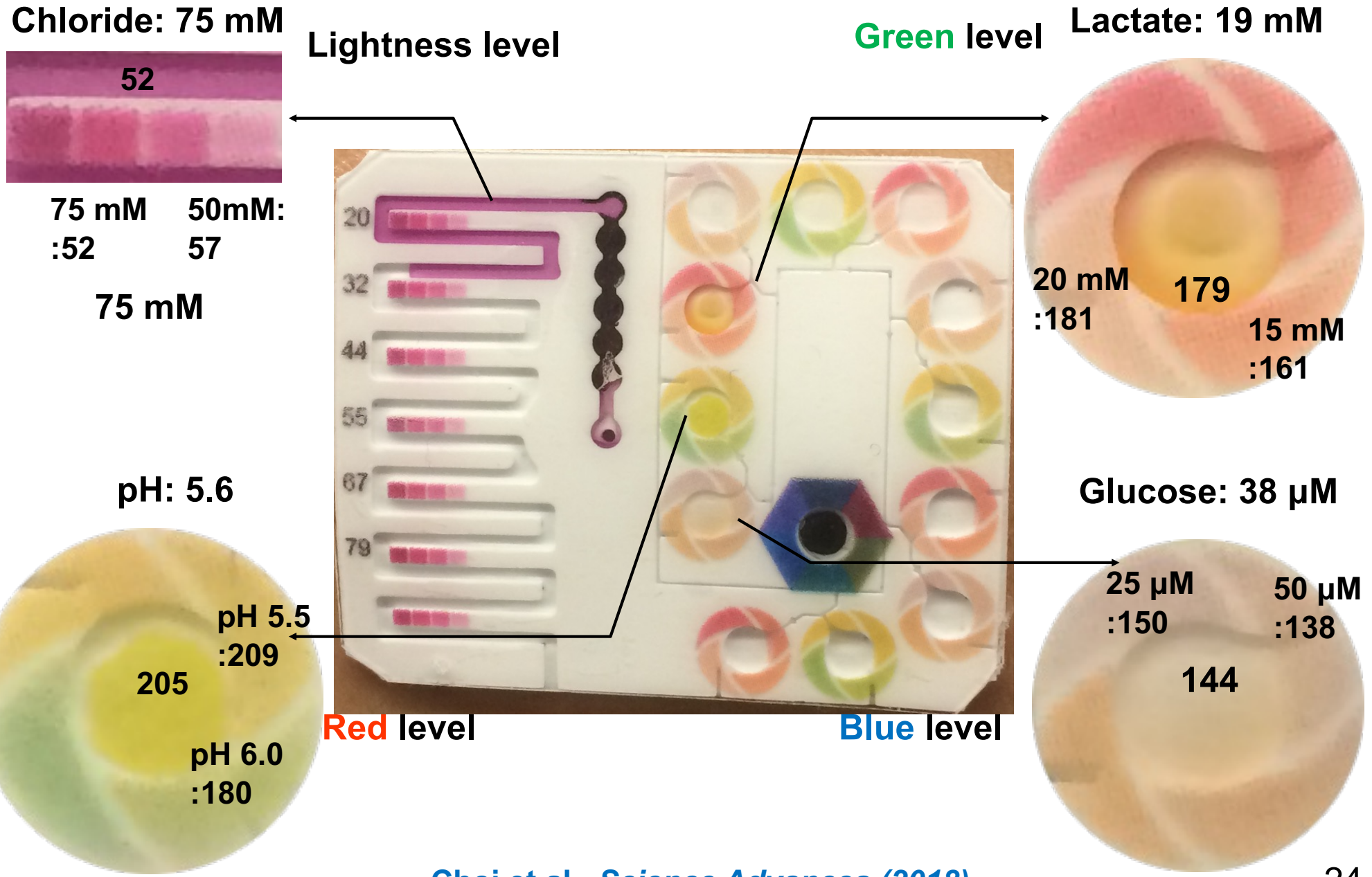


Calculating Conc.



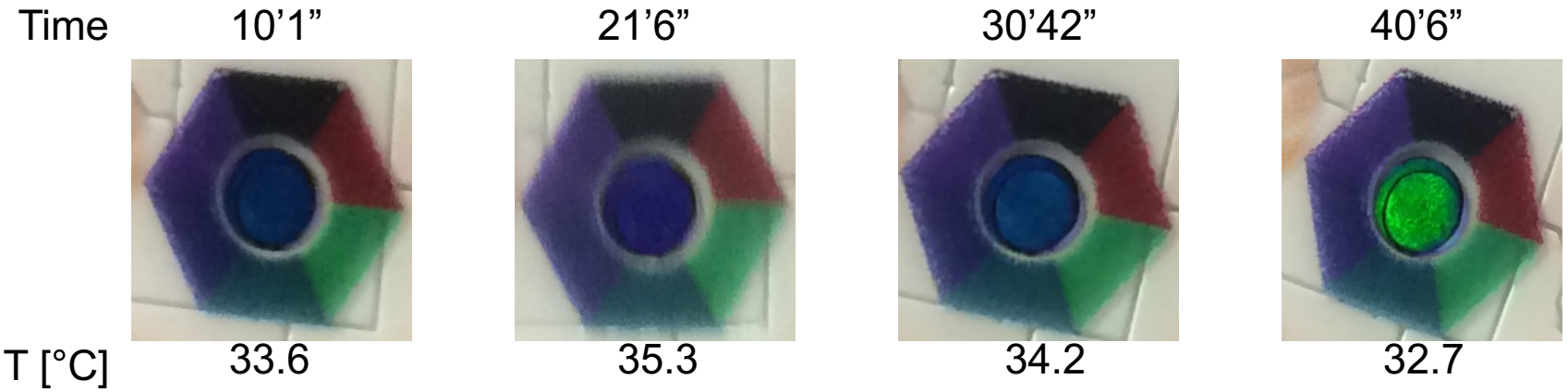
PhotoShop® also works

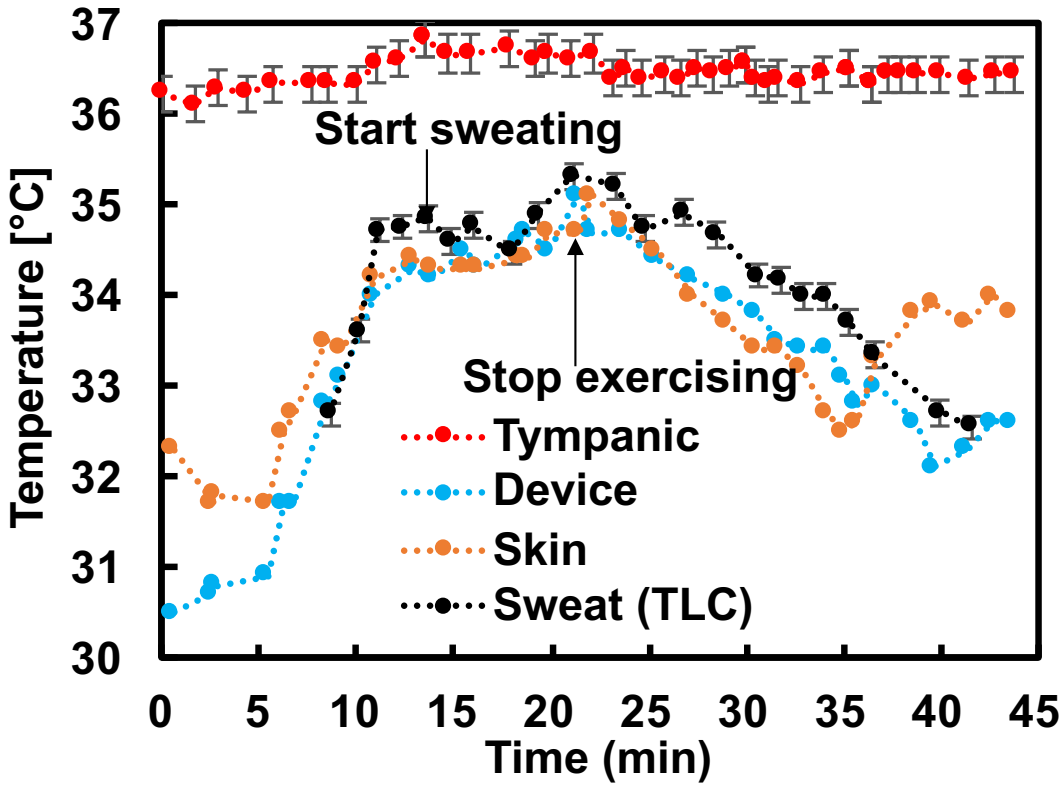
Sweat Analysis by Color



Choi et al., *Science Advances (2018)*

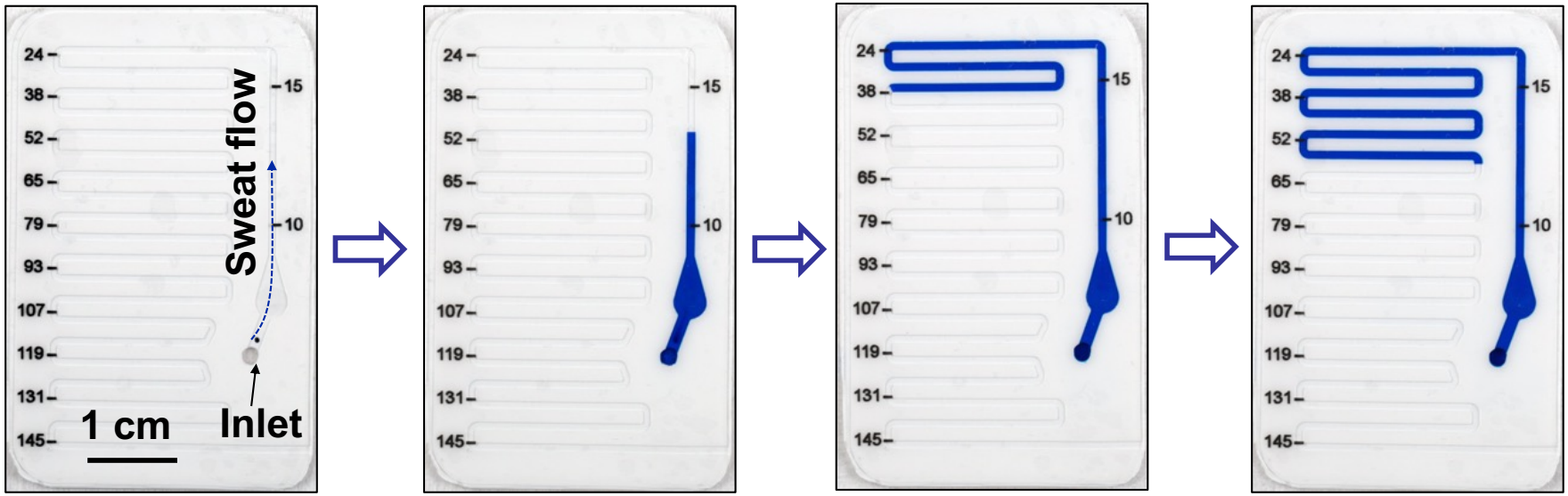
Sweat Temperature and Skin Temperature



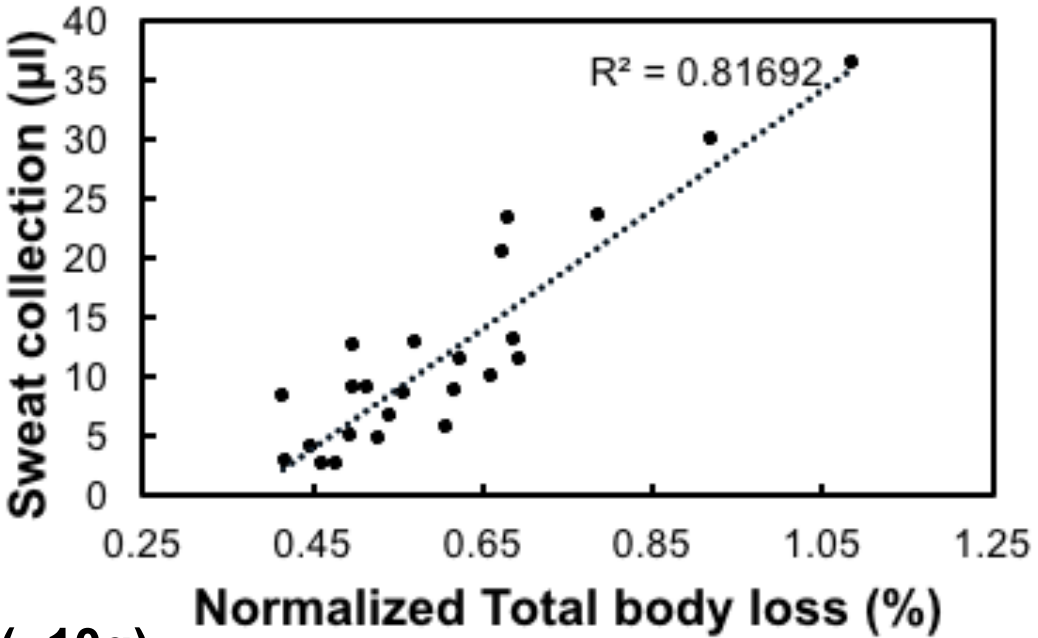


Choi et al., *ACS Sensors* (2019)

Local Sweat Loss and Total Body Loss

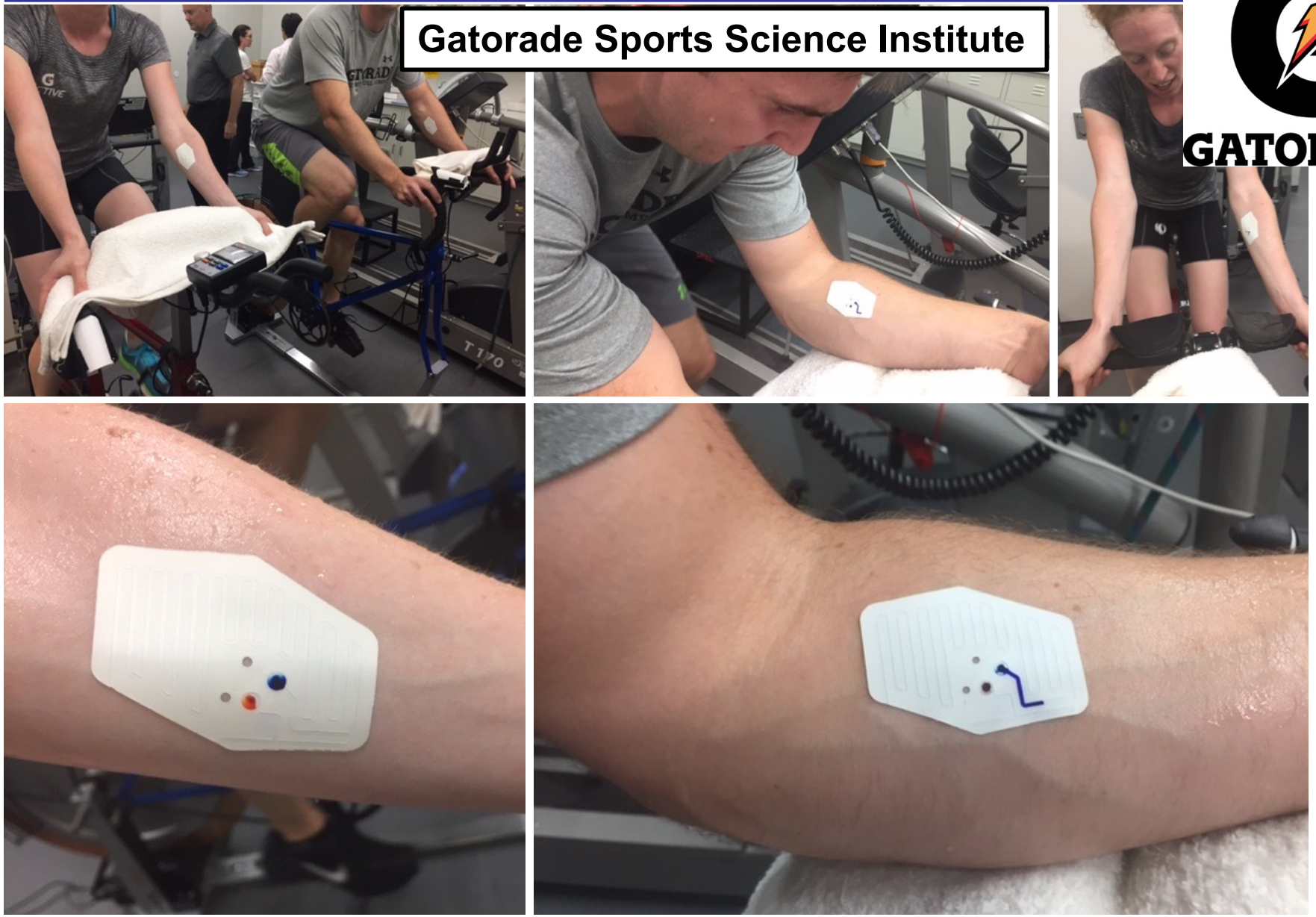


High Precision
Weighing Scales (~10g)



Choi et al., *Science Advances (2018)* 26

Sweat Rate and Chloride Field Studies



GX SWEAT PATCH

Personalized hydration is now available to all athletes.

https://www.gatorade.com/gx/gx-sweat-patch

Sweat Devices for Diabetes

Current method: Blood

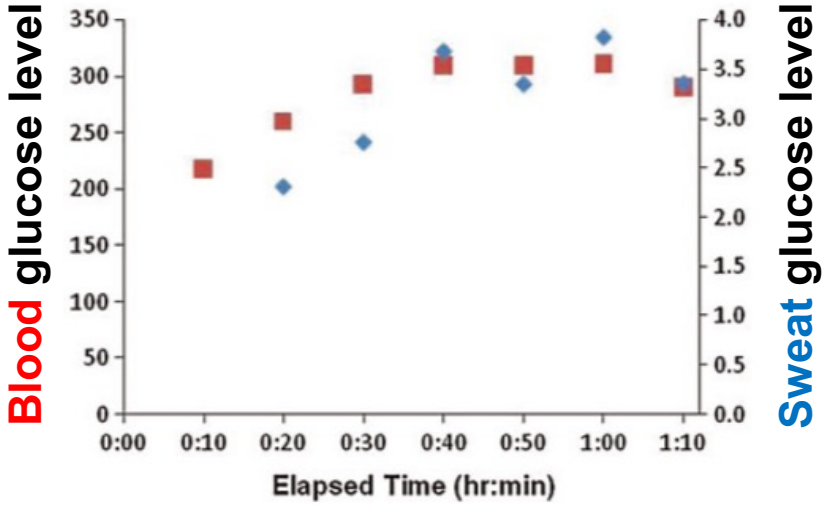
Fast plasma glucose (FPG)
≥126 mg/dl
After 8 hours of fasting

HbA1c (glycated haemoglobin)
≥ 6.5% (140 mg/dl)
Average plasma glucose concentration

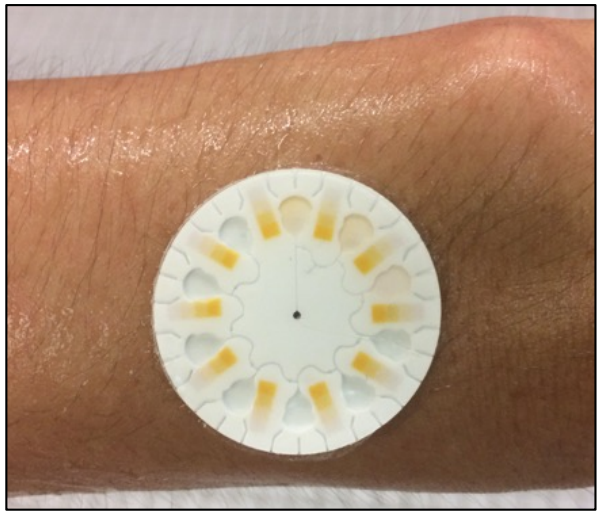
© Ilya Andriyanov / Shutterstock

Blood + Needle

New method: Sweat



Diabetes Technol. Ther. 2012

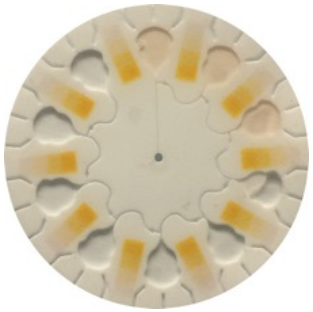


Sweat + Patch

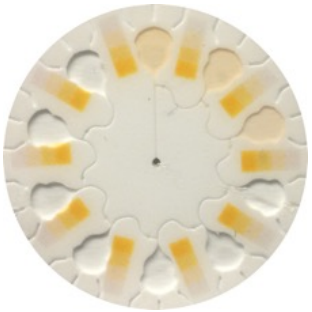
In situ Sweat Glucose Test with Blood

Glucose Tolerance Test

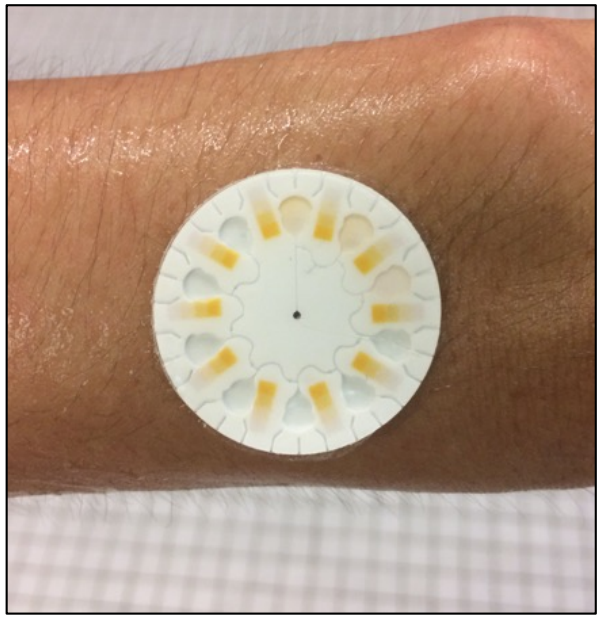
8 hr fasting	15 min Sauna session	Drinking glucose	2 hrs	20 min Sauna session



22 ± 0.5 μM

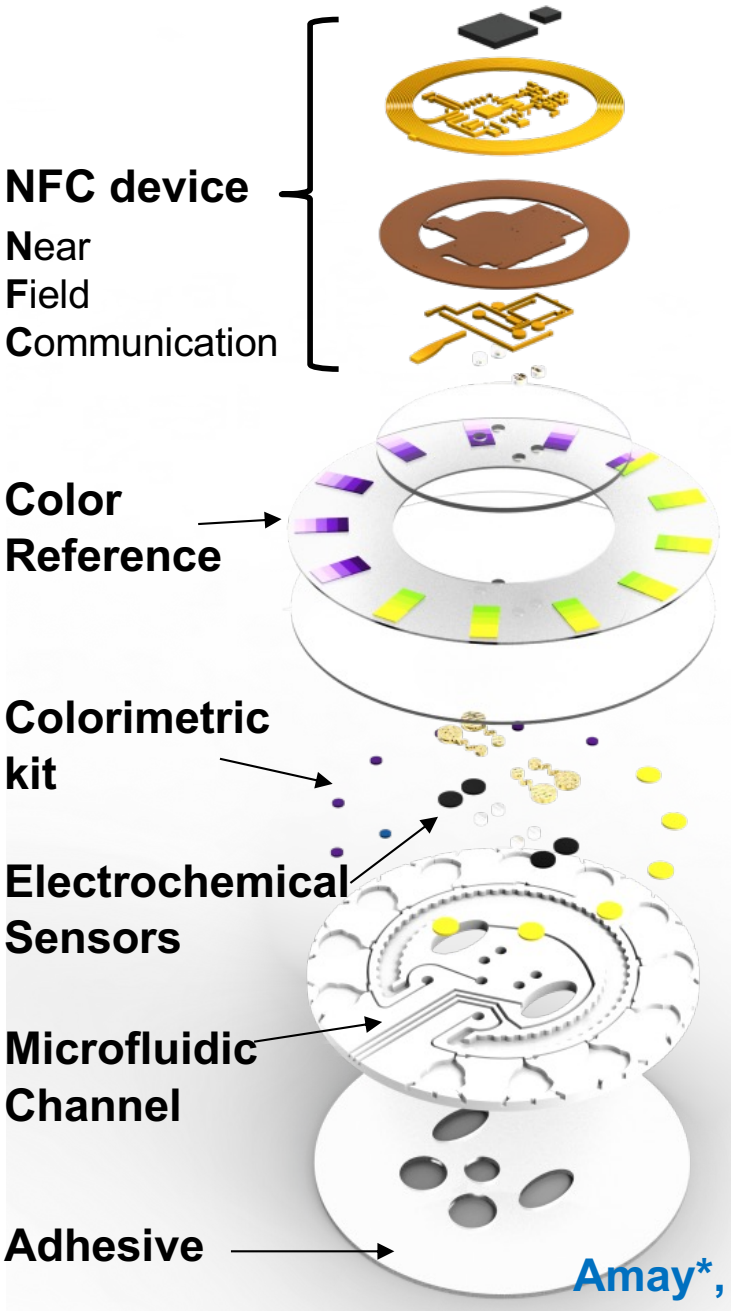


36 ± 0.6 μM

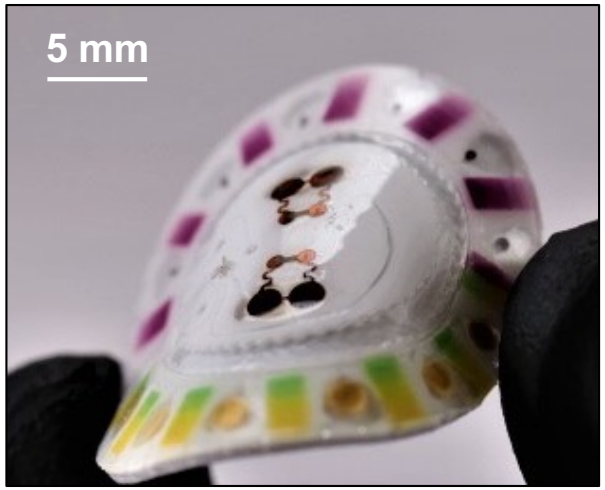


Non-Invasive
Glucose Level Monitoring

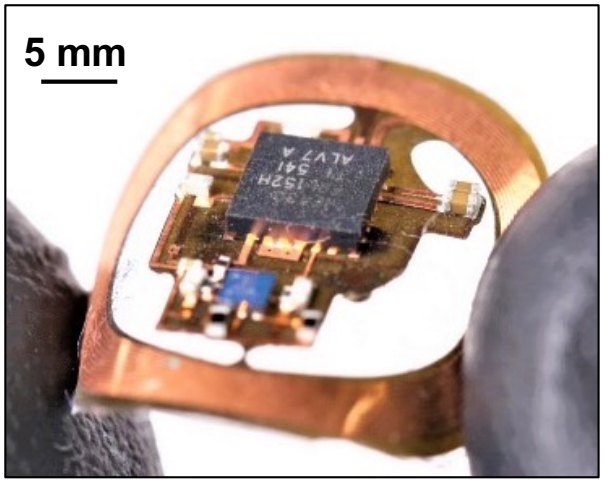
Hybrid System of Microfluidics and Electronics



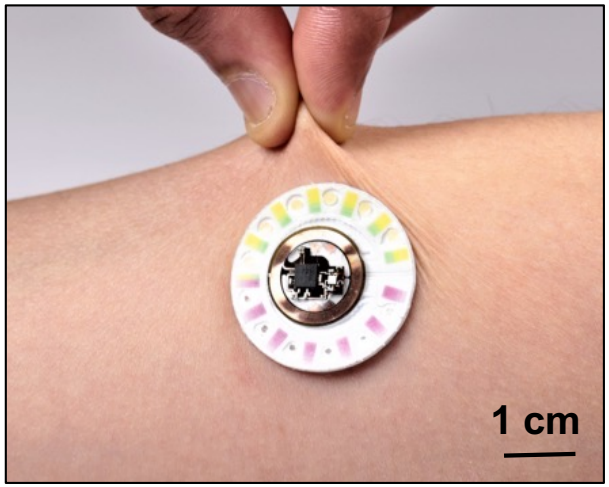
Soft Microfluidics



Flexible Electronics



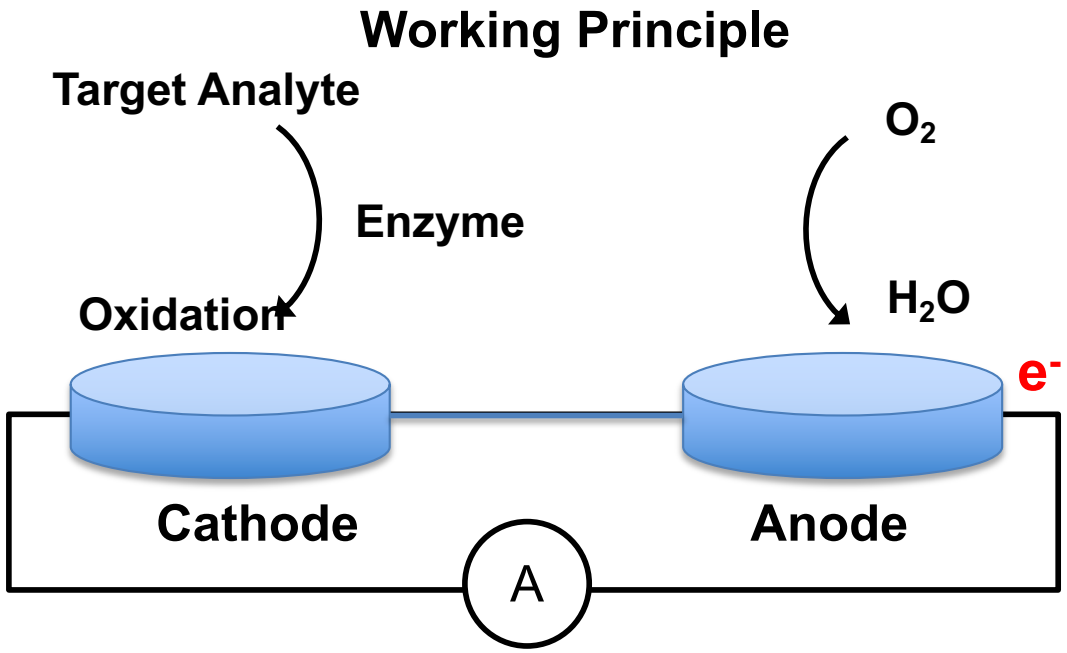
Skin interface

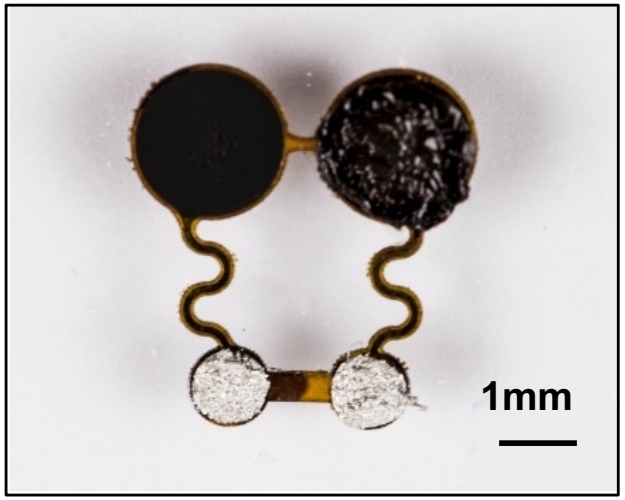


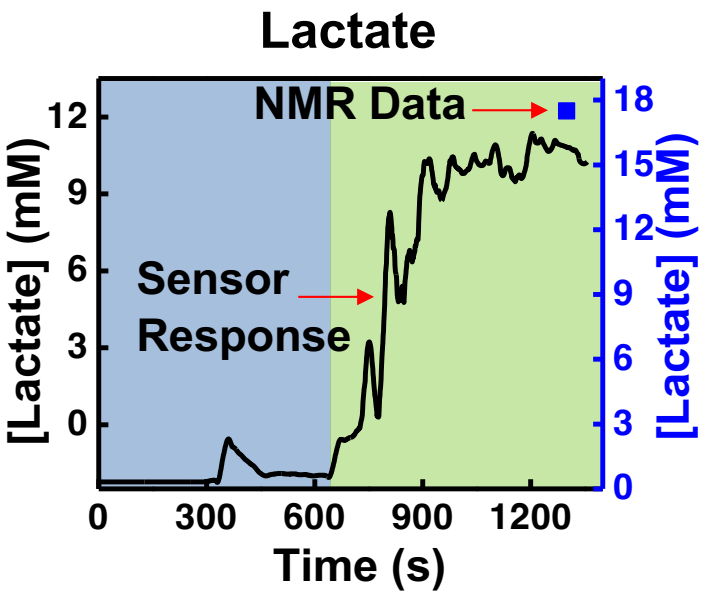
Wireless communication

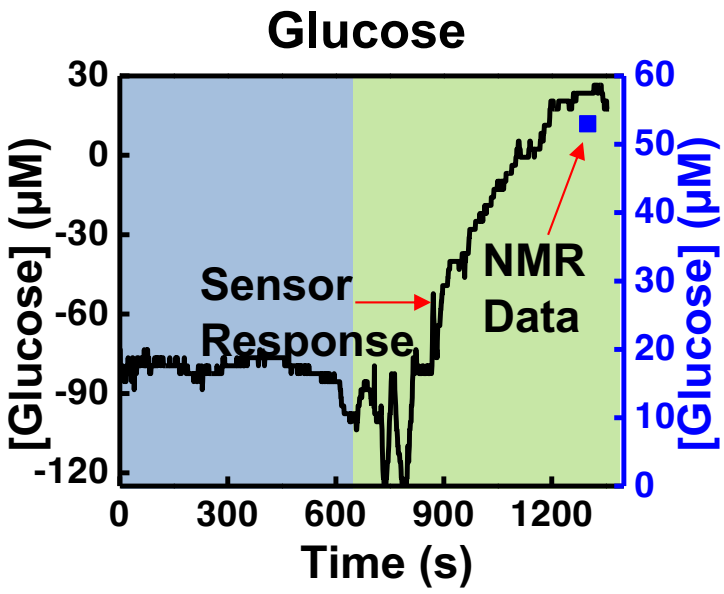
Amay*, Gutruf*, Choi* *et al.*, *Science Advances (2019)*

Amperometric Electrochemical Sensors



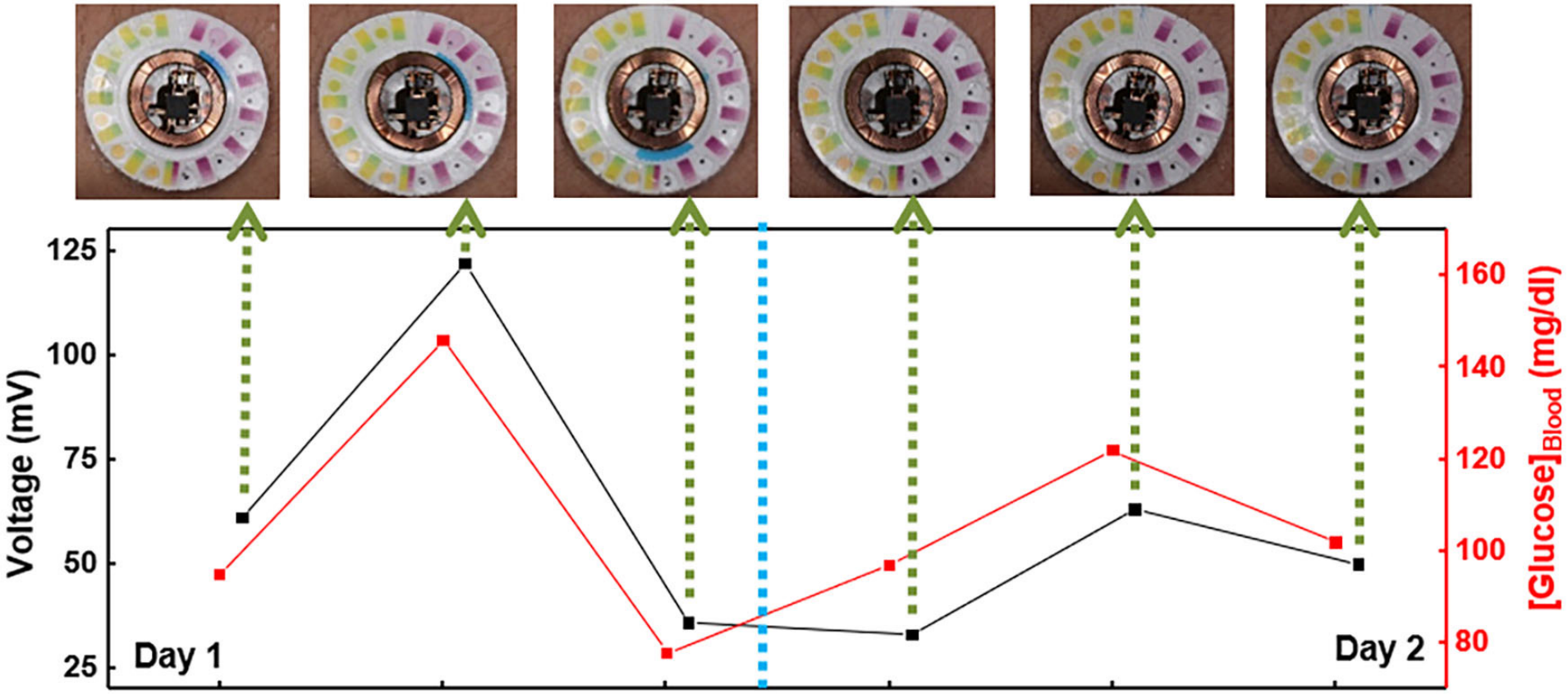






Amay*, Gutruf*, Choi* *et al.*, *Science Advances (2019)*

Long term test with blood glucose level



Amay*, Gutruf*, Choi* *et al.*, *Science Advances (2019)*

Approaching to the market

Patent of sweat sensor

특허증

CERTIFICATE OF PATENT

특 허 Patent Number 제 10-2334848 호

출원번호 Application Number 제 10-2020-0071849 호

출원일 Filing Date 2020년 06월 12일

등록일 Registration Date 2021년 11월 30일

발명의명칭 Title of the Invention

바이오 센싱 모듈, 이의 동작 방법, 및 이를 이용하는 바이오 센싱 시스템

특허권자 Patentee

국민대학교산학협력단(114471-*******)

서울특별시 성북구 정릉로 77 (정릉동, 국민대학교)

발명자 Inventor

최정일(821220-*******)

서울특별시 관악구 남부순환로230길 93 반석불레스빌 602호

위의 발명은 「특허법」에 따라 특허원부에 등록되었음을 증명합니다.

This is to certify that, in accordance with the Patent Act, a patent for the invention has been registered at the Korean Intellectual Property Office.

특허청 Korean Intellectual Property Office

2021년 11월 30일

특허청장 COMMISSIONER, KOREAN INTELLECTUAL PROPERTY OFFICE 김 용 래

QR코드로 현재기준 등록사항을 확인하세요

Meeting with ㈜ 올메디쿠스
2021.11.29

allmedicus

Wearable Sweat Sensor for Insensible Sweat

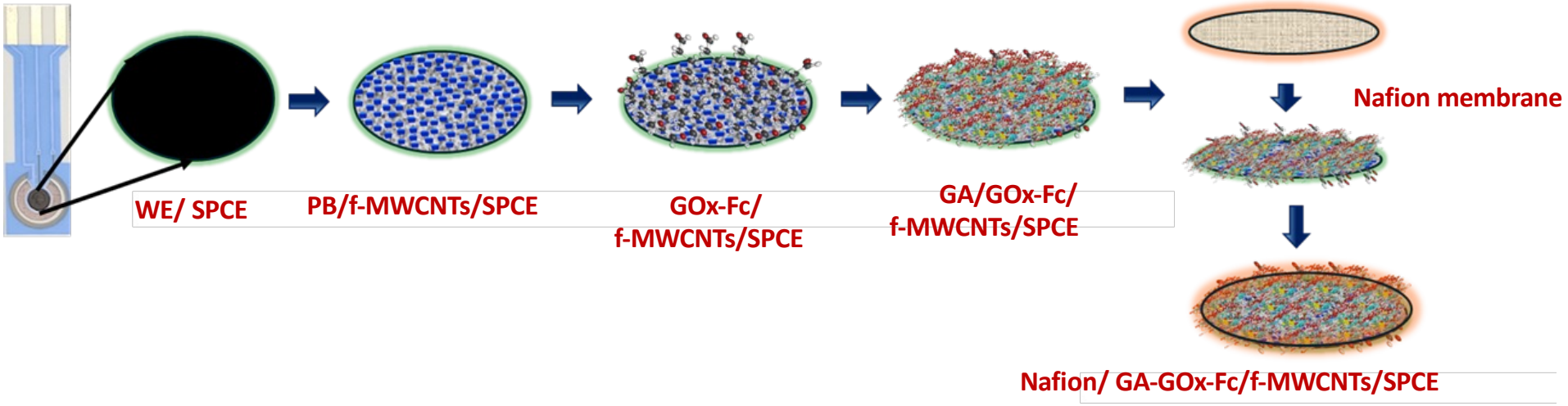
일상생활 속 흘리는 땀

미세유체 기반 센서를 통해 땀 포도당 분석

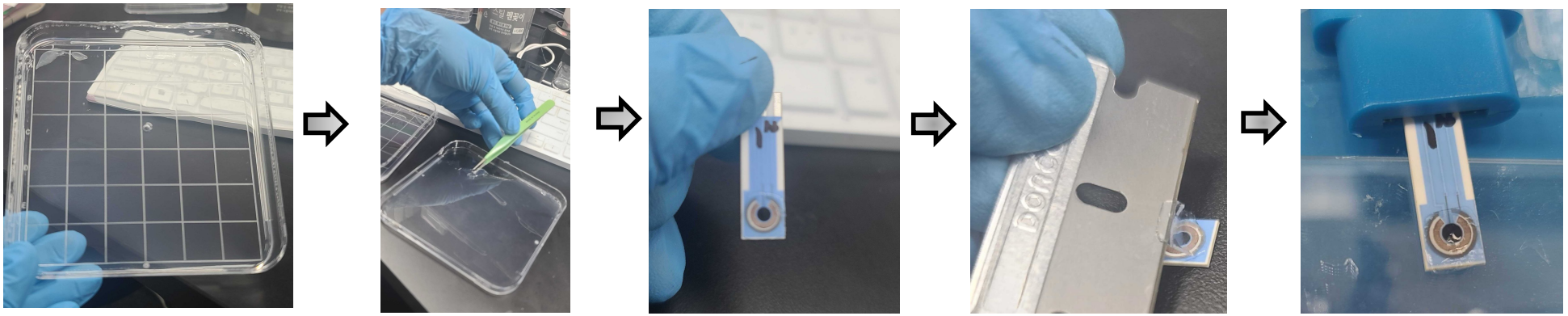
스마트폰으로 혈당 주기적 확인

Insensible Sweat Glucose Sensor

Fabrication of Glucose Sensor

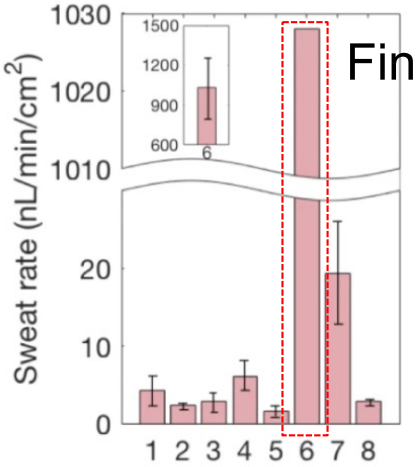


Preparation of PVA- Agarose Hydrogel



Unpublished

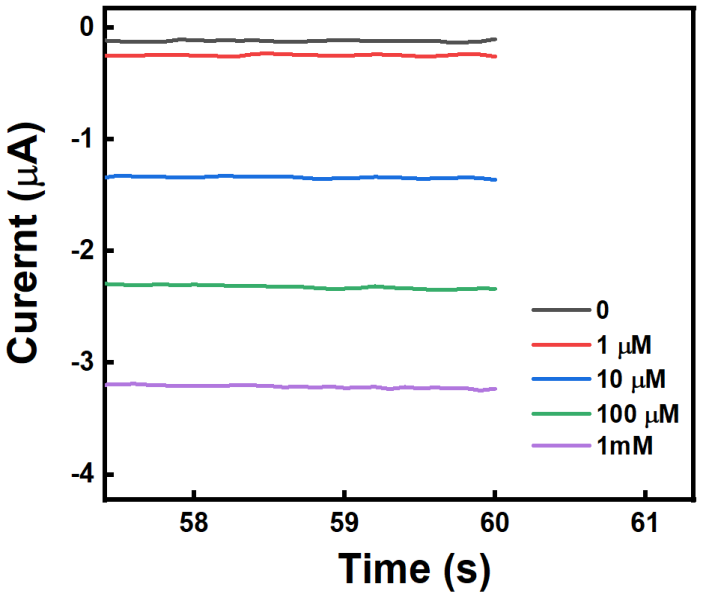
Performance of Sweat Glucose Sensor



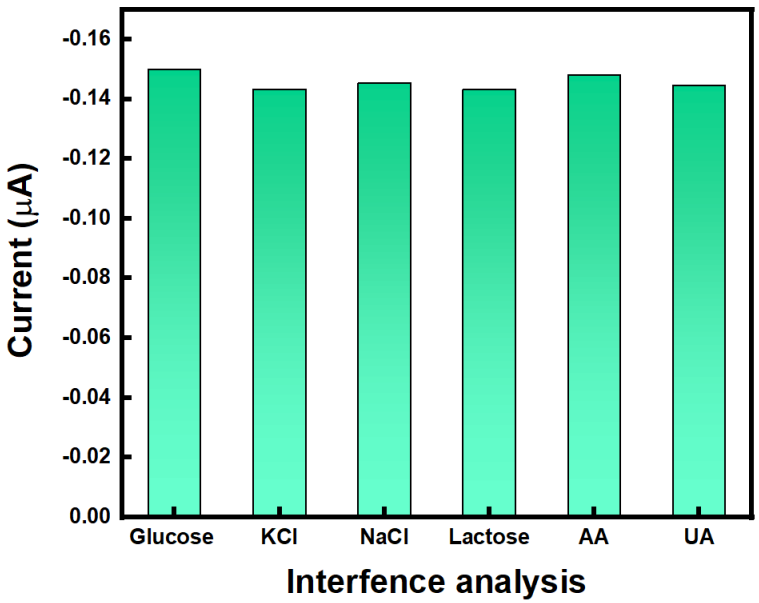
Finger

Nature Com. (2021)

Using 1 ul of
Artificial Sweat

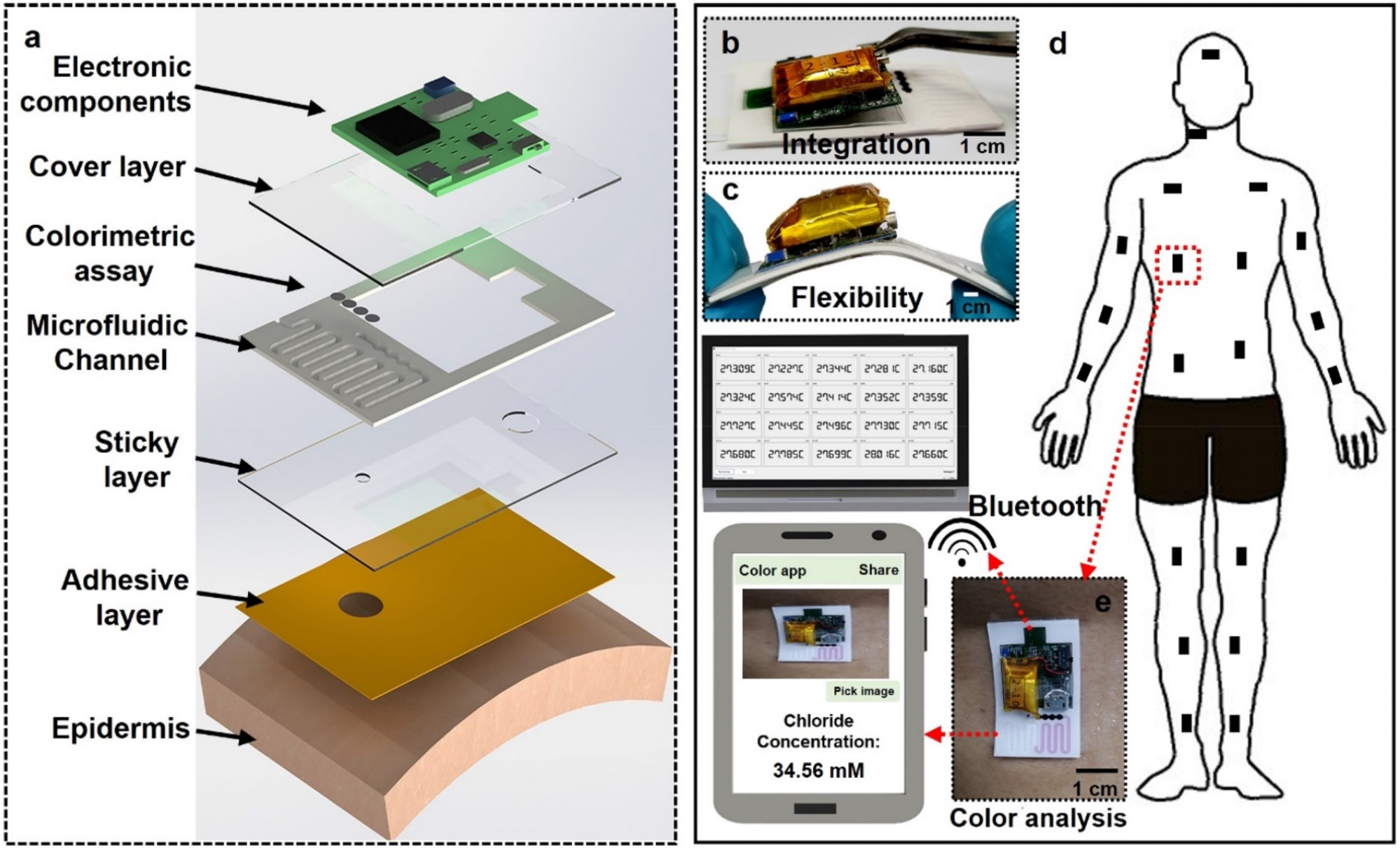


Electrochemical Signal
from difference Glucose Concentration



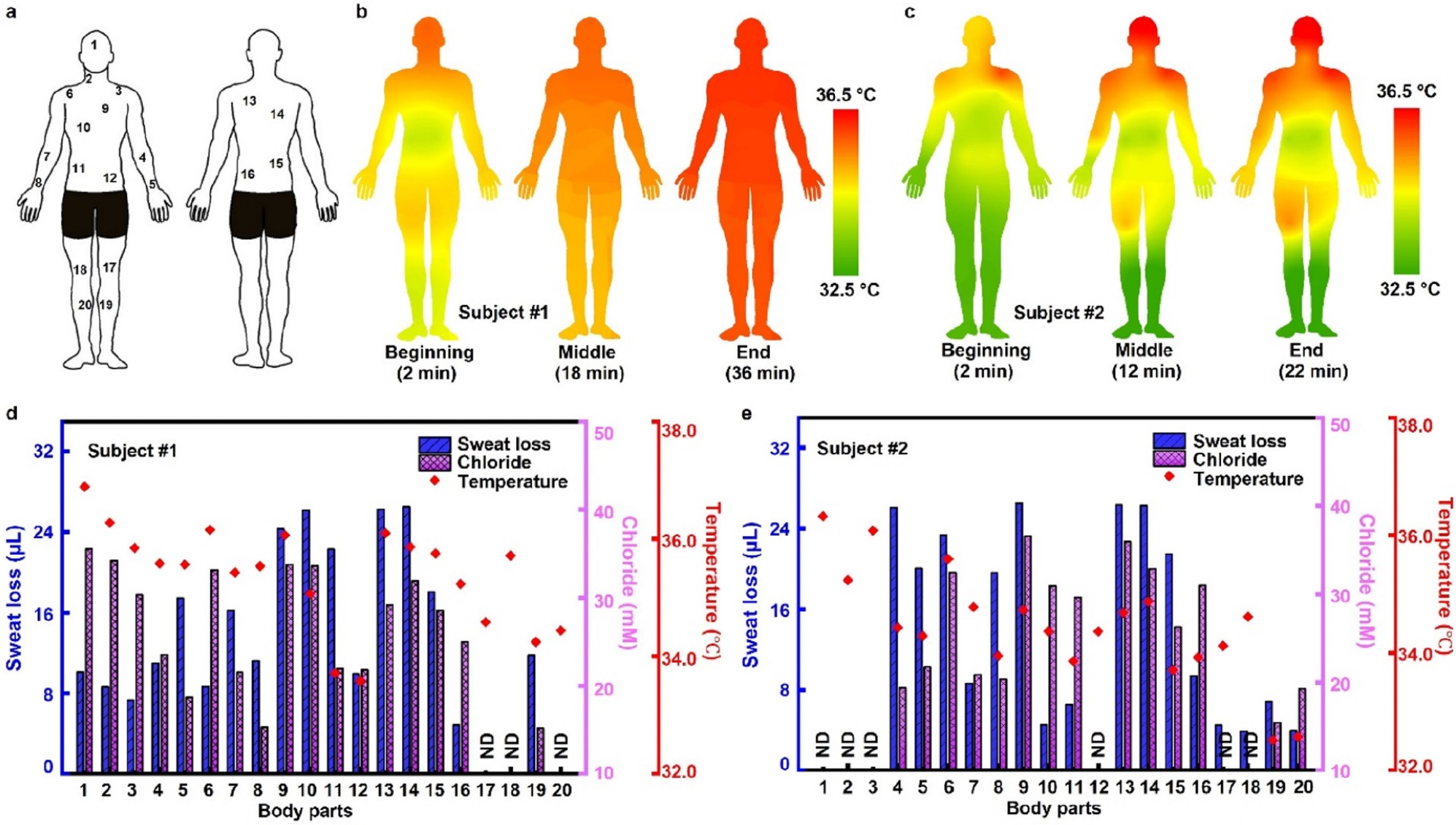
Unpublished

Measuring both Physical and Chemical Signal



Alam, Choi, *ACS Sensors*, 2023

Mapping sweat & body temperature



Alam, Choi, *ACS Sensors*, 2023

미세먼지, 피부, 화장품

www.signaturemg.co.kr

산성 피부 pH 5 이하 약산성 피부 pH 5.5 알칼리성 피부 pH 7.5 이상

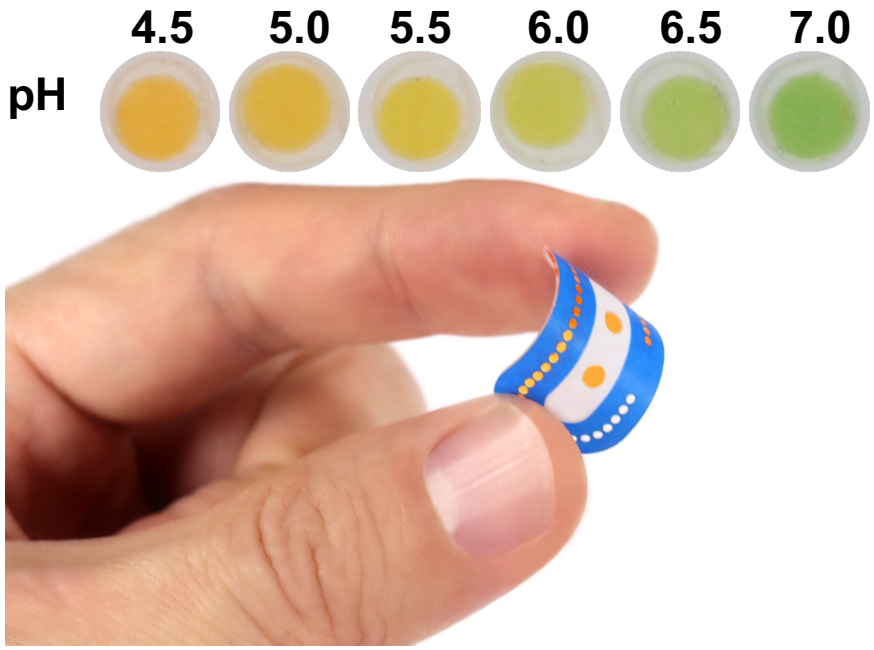
맞춤형 기초화장품 체험 전시
(출처: 뷰티경제)

HANNA 스킨측정용 PH측정기 PH-99181 피부산도측정기

₩570,000 무료 배송 G마켓

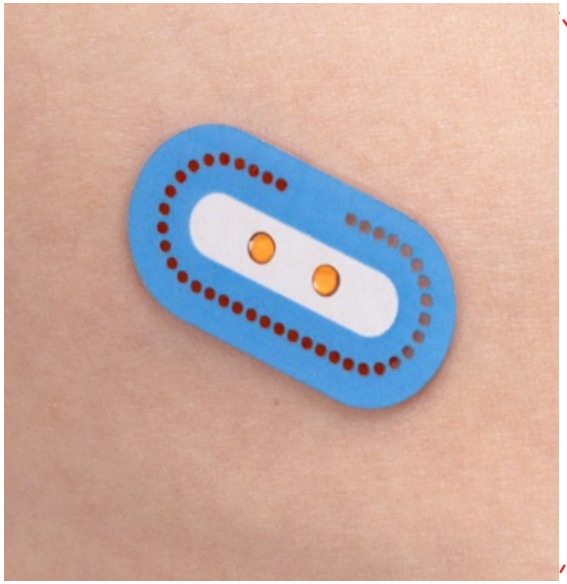
HANNA 스킨측정용 **PH**측정기 **PH**-99181 피부산도측정기

Wearable Skin pH Sensor with L'Oréal

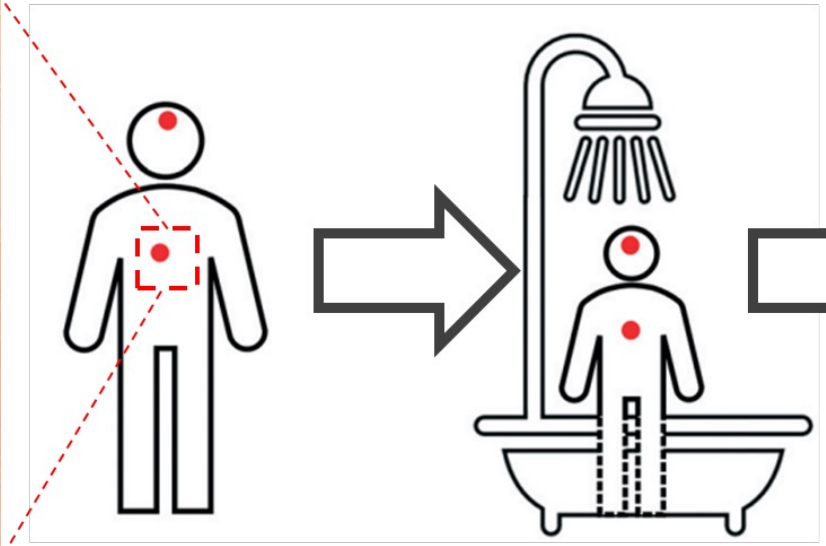


웨어러블 땀 센서를 이용한 pH 측정

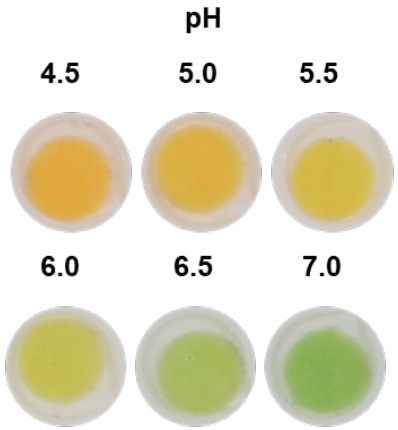
1. 스킨 패치형태의 땀 분석 센서



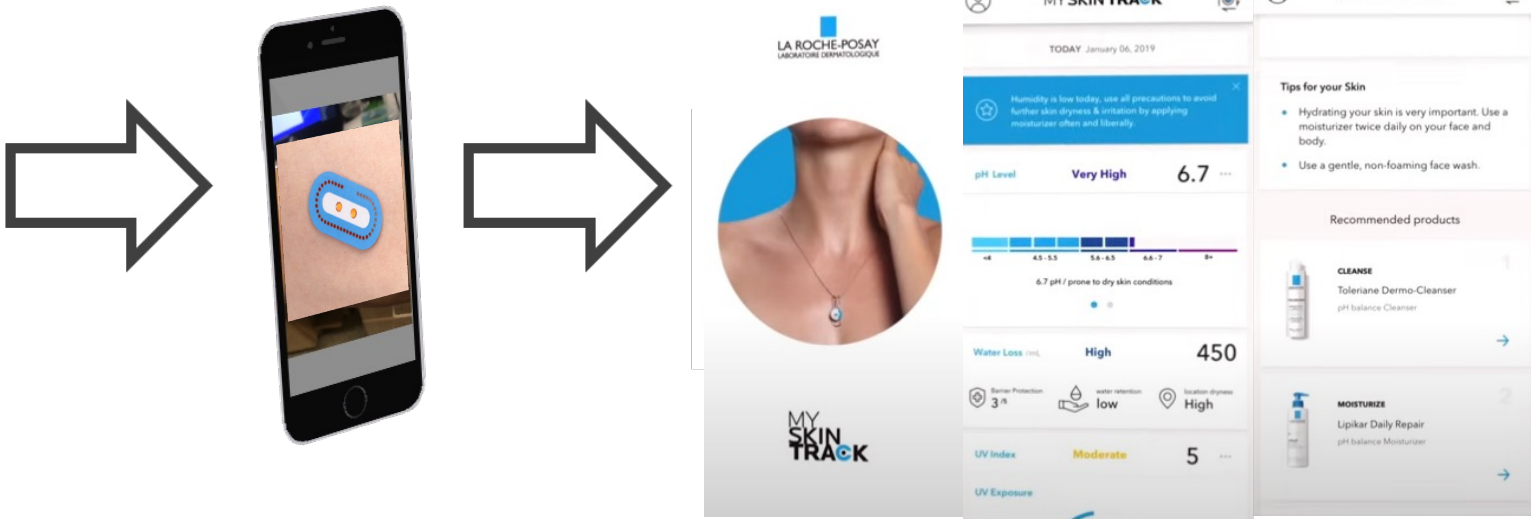
2. 온수 샤워 동안 땀을 채취 및 분석



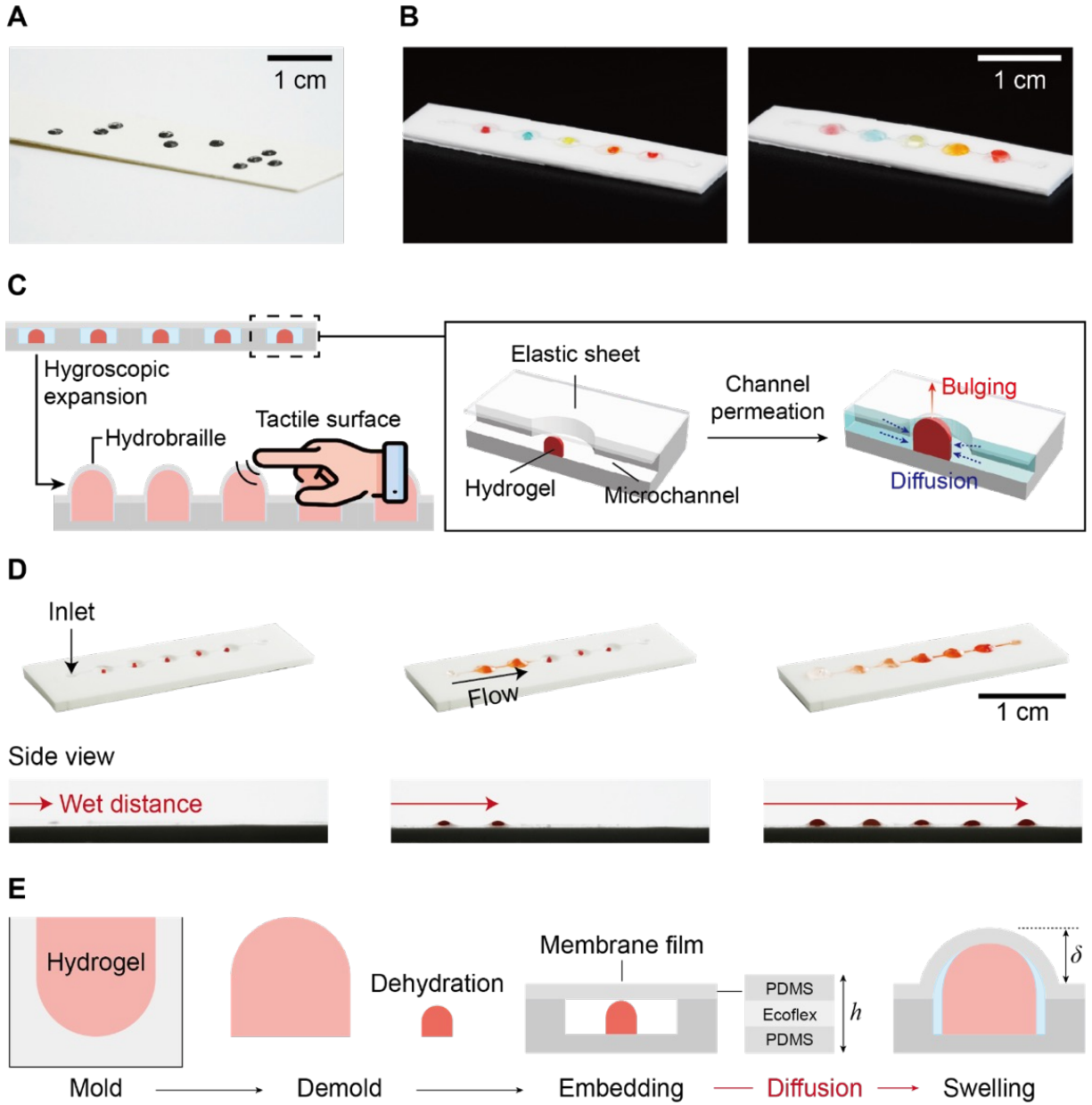
3. pH 센서의 색상 변화



4. 스마트폰 앱을 통한 pH 분석 및 적합한 화장품 추천



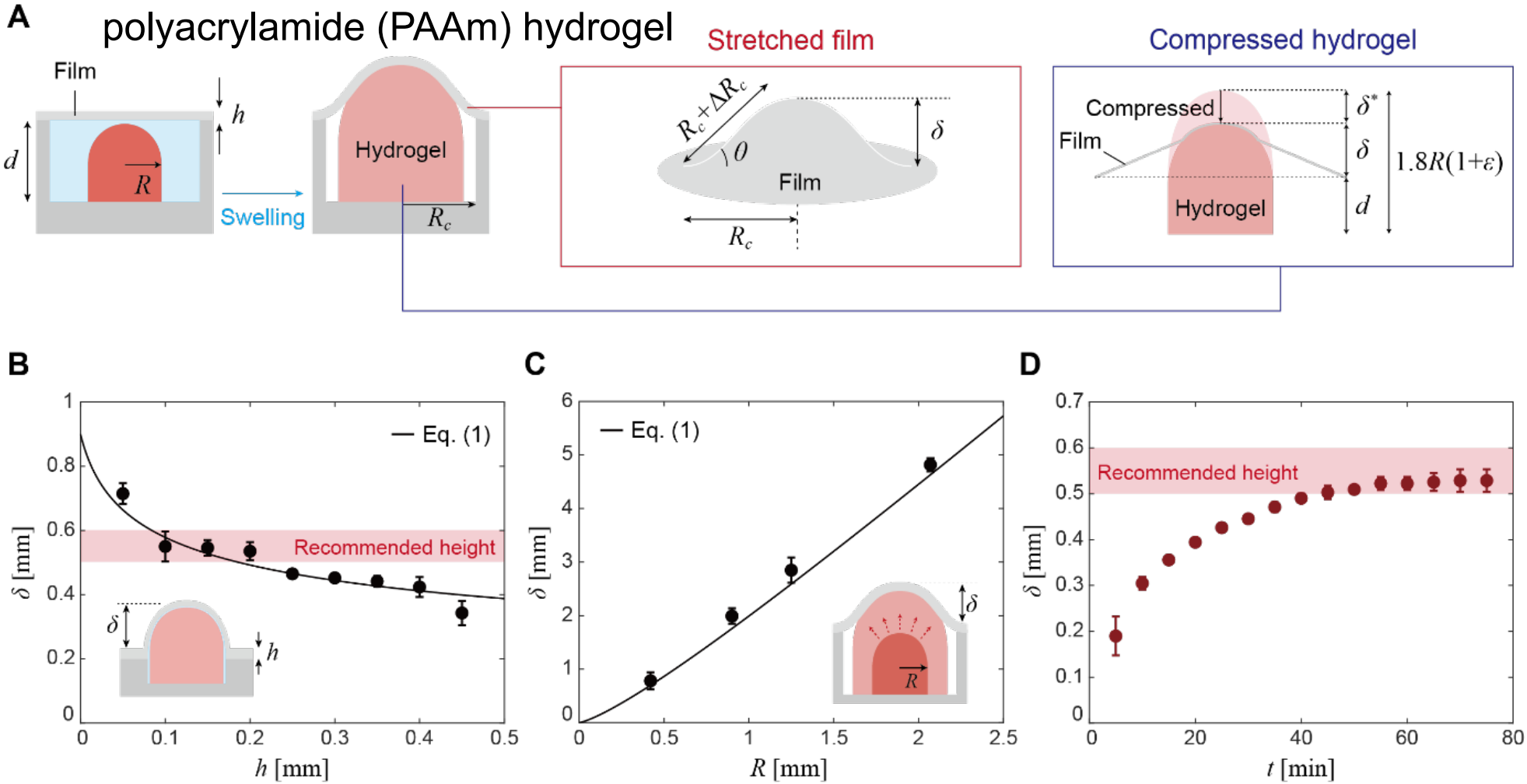
Hydrobraille: A wearable tactile sensor



Collaboration with Prof. Jonghyun Ha at Ajou Univ

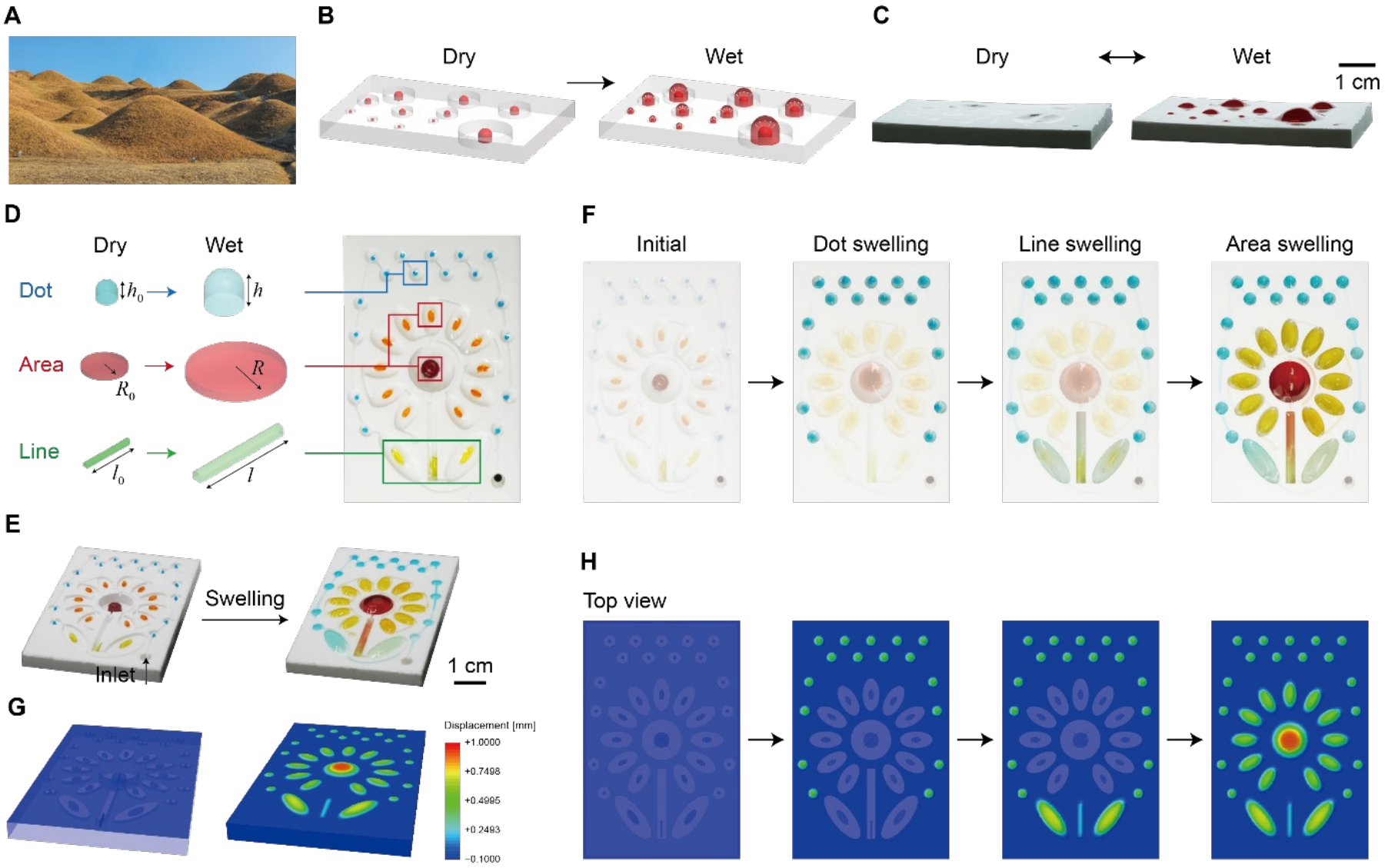
Under review

Mechanical modeling and analysis of Braille



- PAAm hydrogel's crosslinked network with hydrophilic amide groups rapidly absorbs water while retaining structure.
- After drying, it shrinks, but rehydration causes significant swelling via osmotic and hydrophilic interactions.

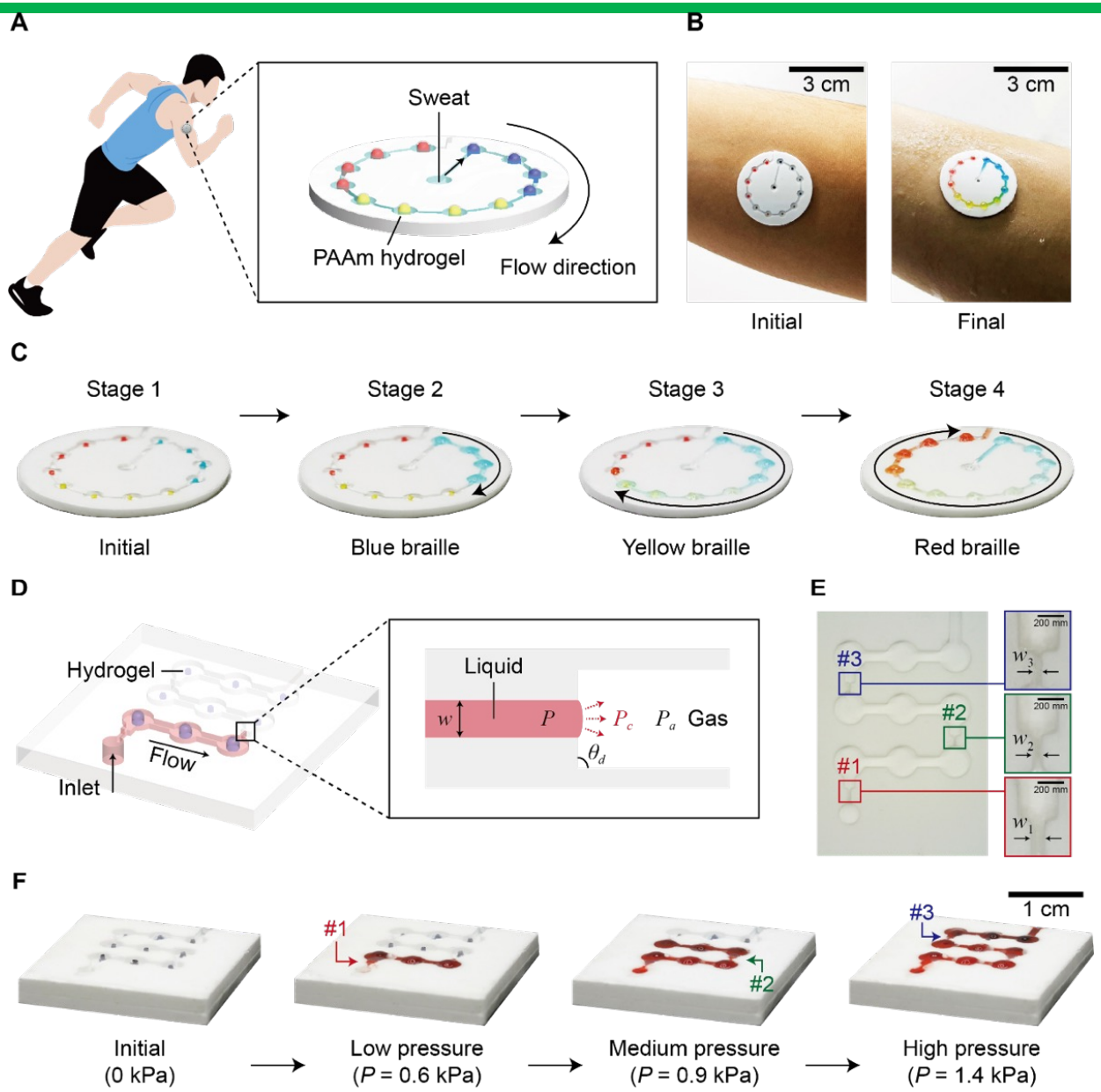
Hydrogel-actuated tactile morphing surfaces



Collaboration with Prof. Jonghyun Ha at Ajou Univ

Under review

Applications of the hydrogel-based Braille



Collaboration with Prof. Jonghyun Ha at Ajou Univ

Under review

Sweat Asymmetry in Stroke Patients

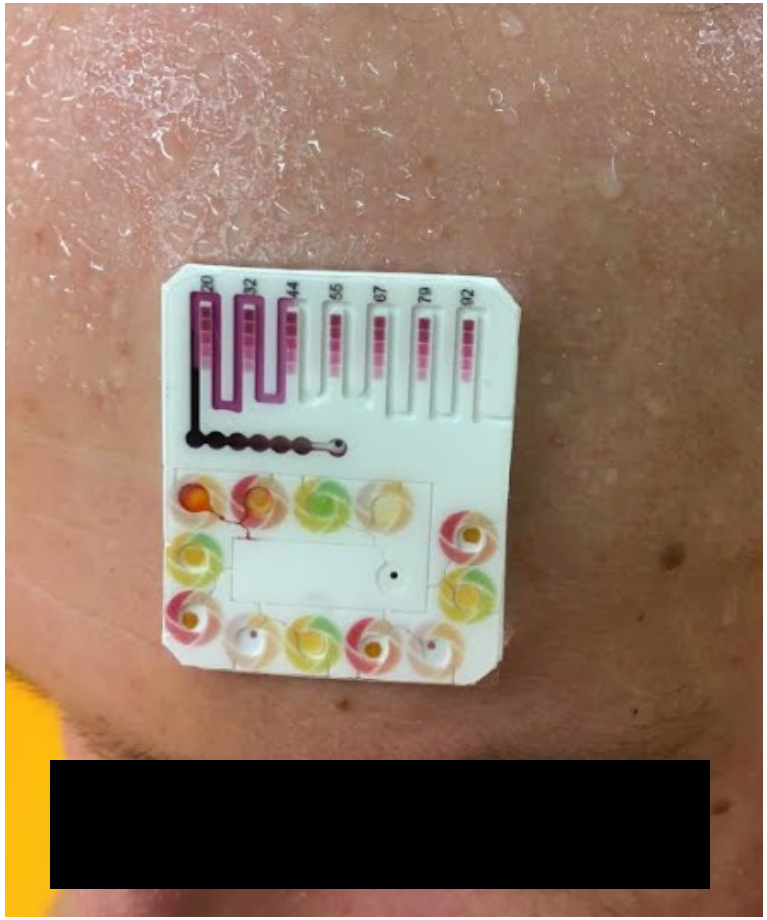
sralab.org

- Sweating dysfunction is frequently encountered in autonomic failure
- Sweat asymmetry observed on forehead, chest, arms, and hand of stroke patients

Korpelainen et al., Neurology (1993)

Sweat Analysis for Rehabilitation

Left forehead



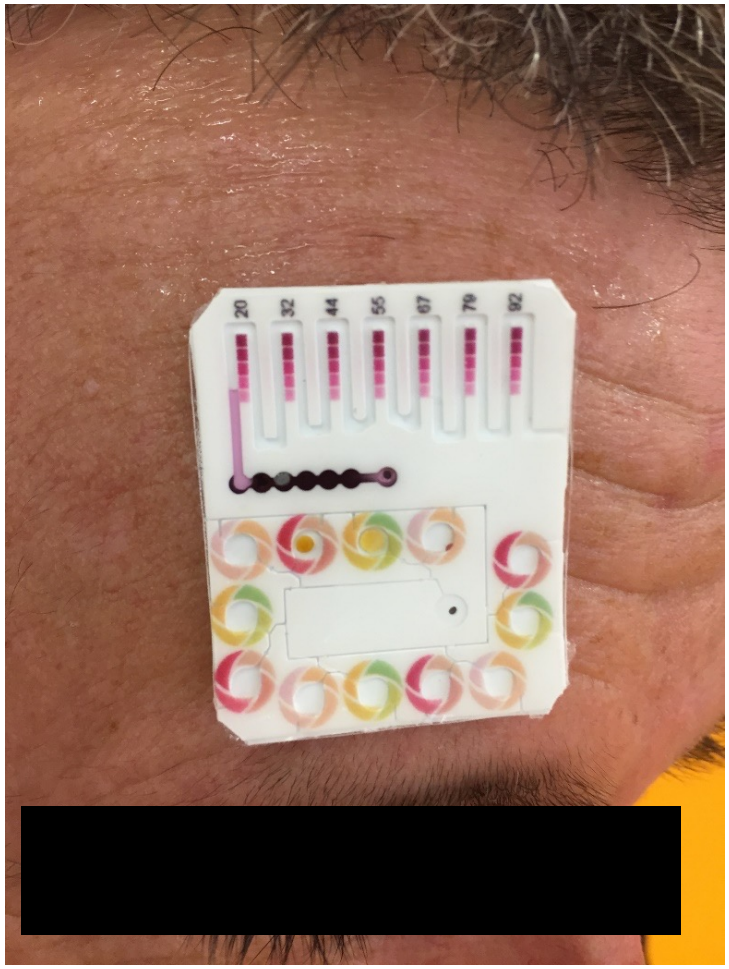
Right forehead

Healthy subjects

Sweat Analysis for Rehabilitation

Left forehead

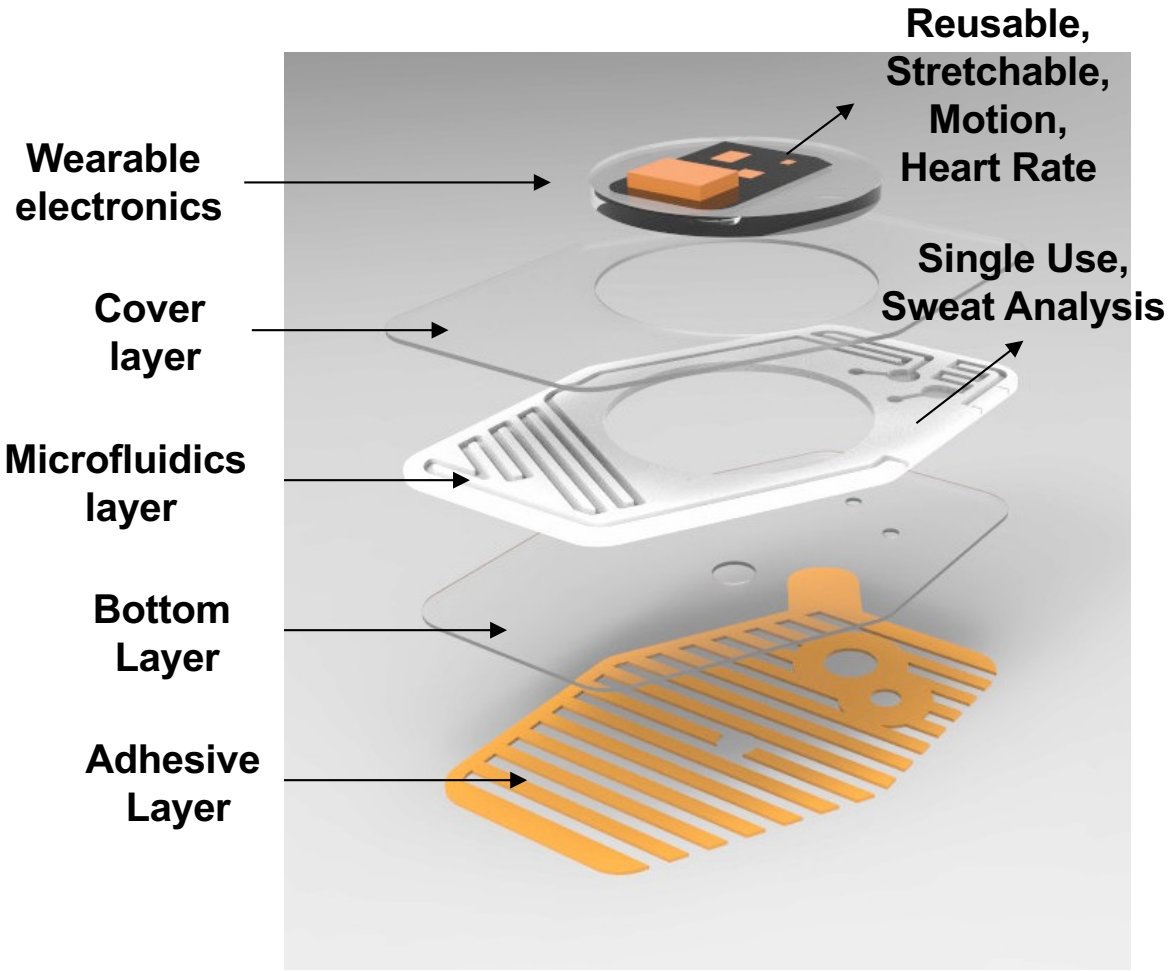
Right forehead

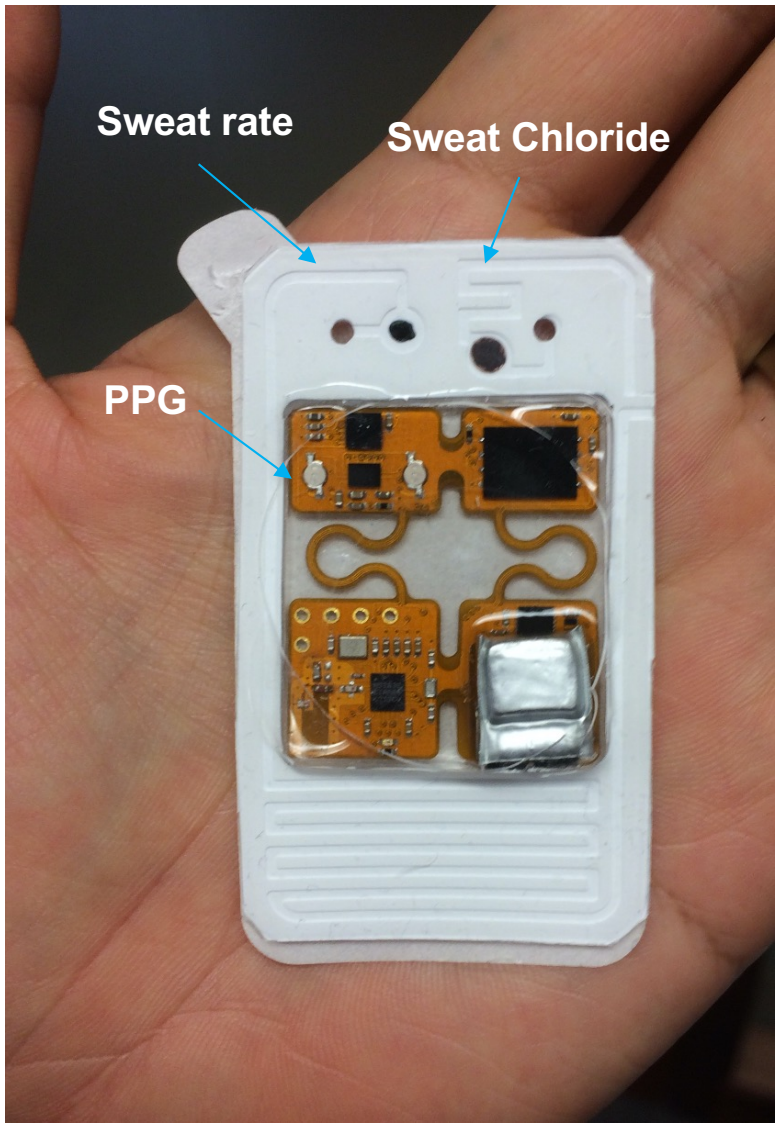


Stroke Patient

Sweat + Motion Analysis for Stroke Patients

Measuring both Physical and Chemical Signal

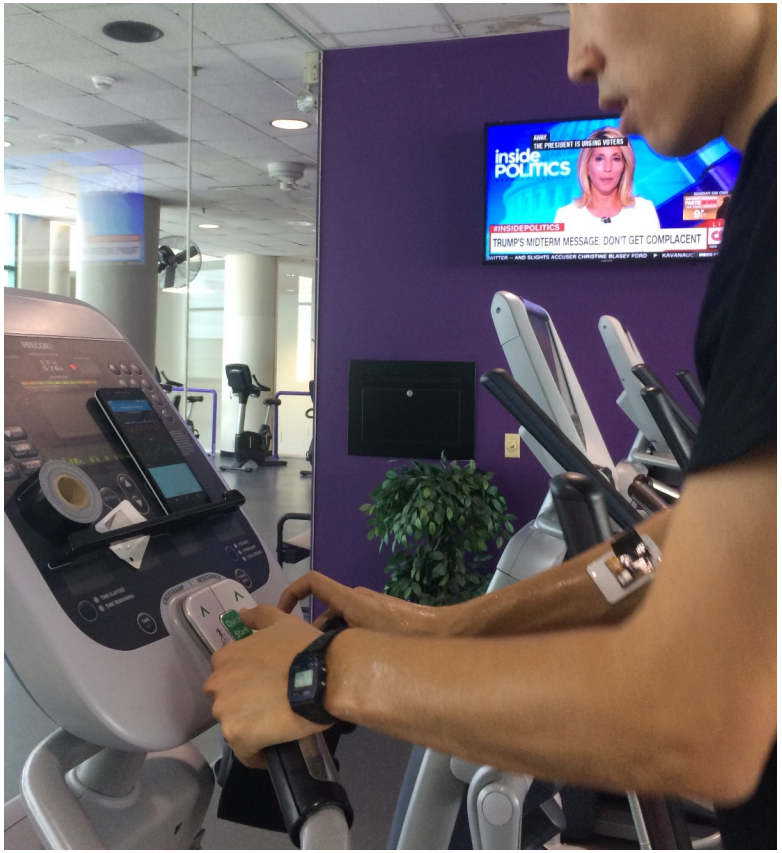




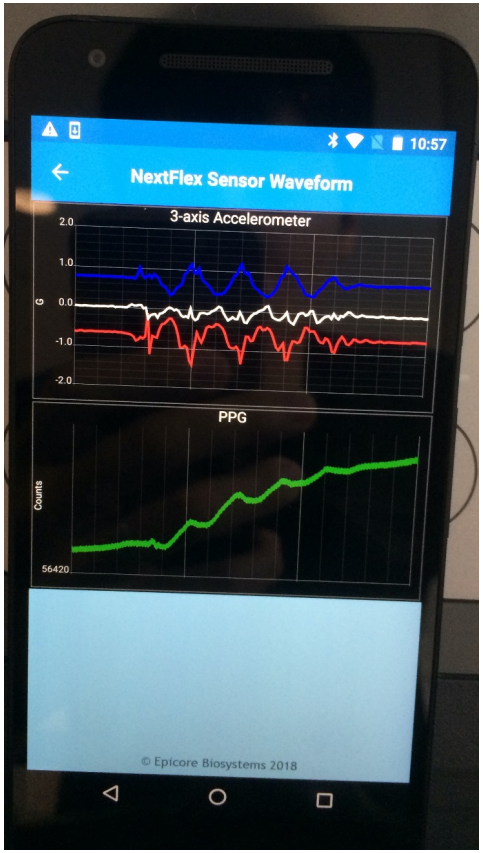
PPG: photoplethysmography

On Body Measurement

Elliptical Exercising



Acceleration & HR



Sweat rate and chloride

Acknowledgment

Collaborators
Prof. John Rogers
Prof. Jonghyun Ha
Prof. Anna Lee
Prof. Janghee Han

Lab Members
Dr. Sekar Madhu
Dr. S. Ramasamy
Giyong Lee
Cheonggyu Lee
Juyoung Hwang
Md. Sajjad Alam
(Currently at Ph.D. course at Pennsylvania State University, USA)

National Research Foundation of Korea

Ministry of Trade, Industry and Energy

아주대학교 AJOU UNIVERSITY