QUERREY SIMPSON INSTITUTE FOR BIOELECTRONICS

Northwestern

Bioelectronics – Academic Research to Commercial Translation

1) Motivation, Perspective, Context
2) Epidermal Electronics: ICU-Grade Monitoring
3) Epidermal Microfluidics: Sweat Biomarker Analysis

John A. Rogers – Northwestern University

Departments of Materials Science and Engineering, Electrical and Computer Engineering, Chemistry, Biomedical Engineering, Mechanical Engineering, Neurological Surgery & Dermatology

jrogers@northwestern.edu

X: @ProfJohnARogers | LinkedIn: ProfJohnARogers

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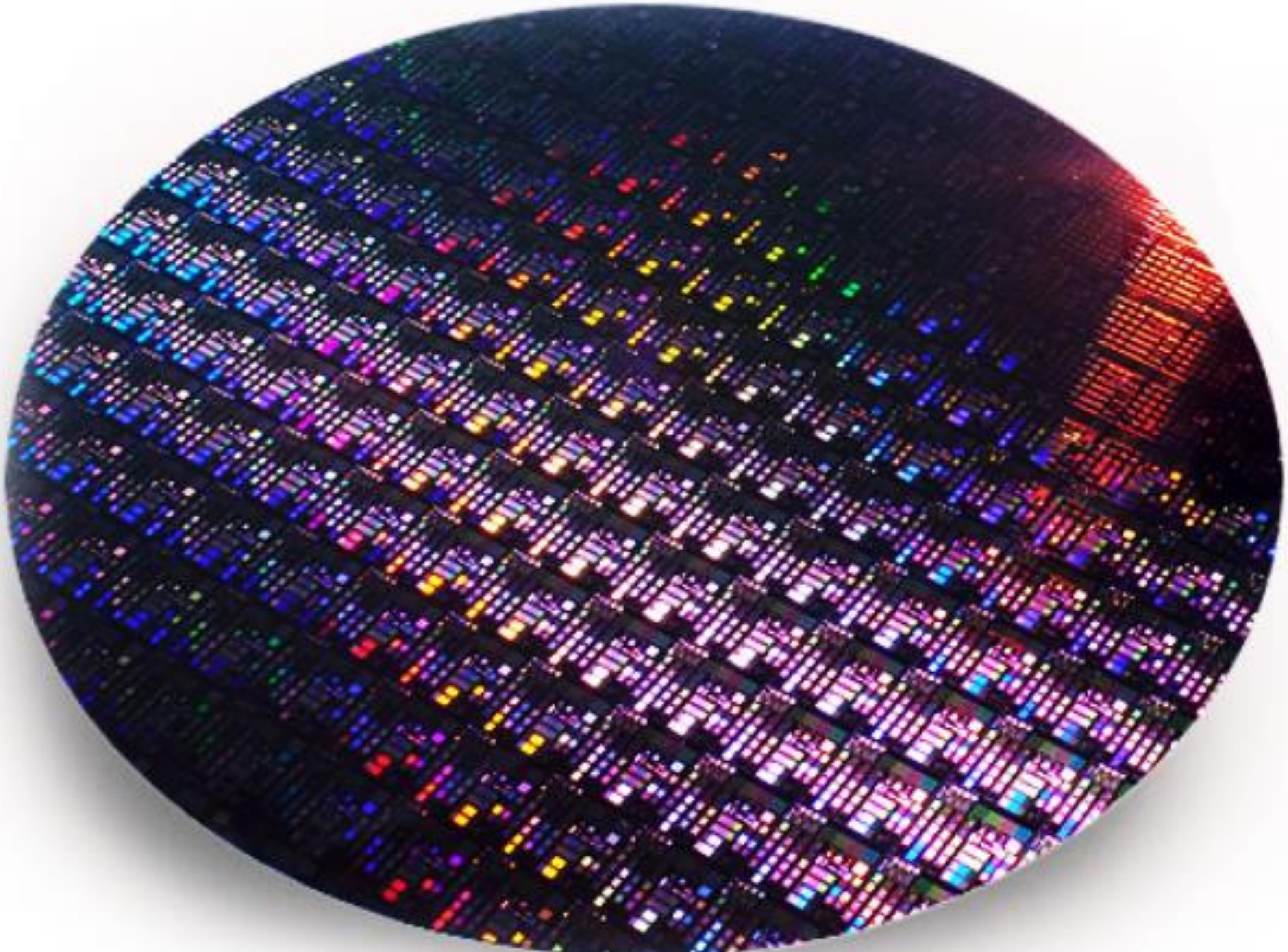

In, On & Around Soft Living Tissues

Academic Research → Commercial Translation

Cell

Science AAAS

nature

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nature materials
ADVANCED MATERIALS
ADVANCED FUNCTIONAL MATERIALS
nature neuroscience

wearifi mm-scale wireless wearables
GATORADE
EPICORE BIOSYSTEMS
U.S. AIR FORCE
L'ORÉAL
SIBEL
LEO

Breakthrough science and engineering

High impact proof of concept and validation

Strong IP protection

Deployment and commercialization

Spinout Companies – ‘Lean’ Mode

Sonica

SIBEL

NeuroLux

wearifi

RHAEOS

EPICORE BIOSYSTEMS

Spinout Companies – 'Lean' Mode

Sonica

SIbEL

NeuroLux

wearifi

RHAEOS

EPICORE BIOSYSTEMS

Bioelectronics – Academic Research to Commercial Development

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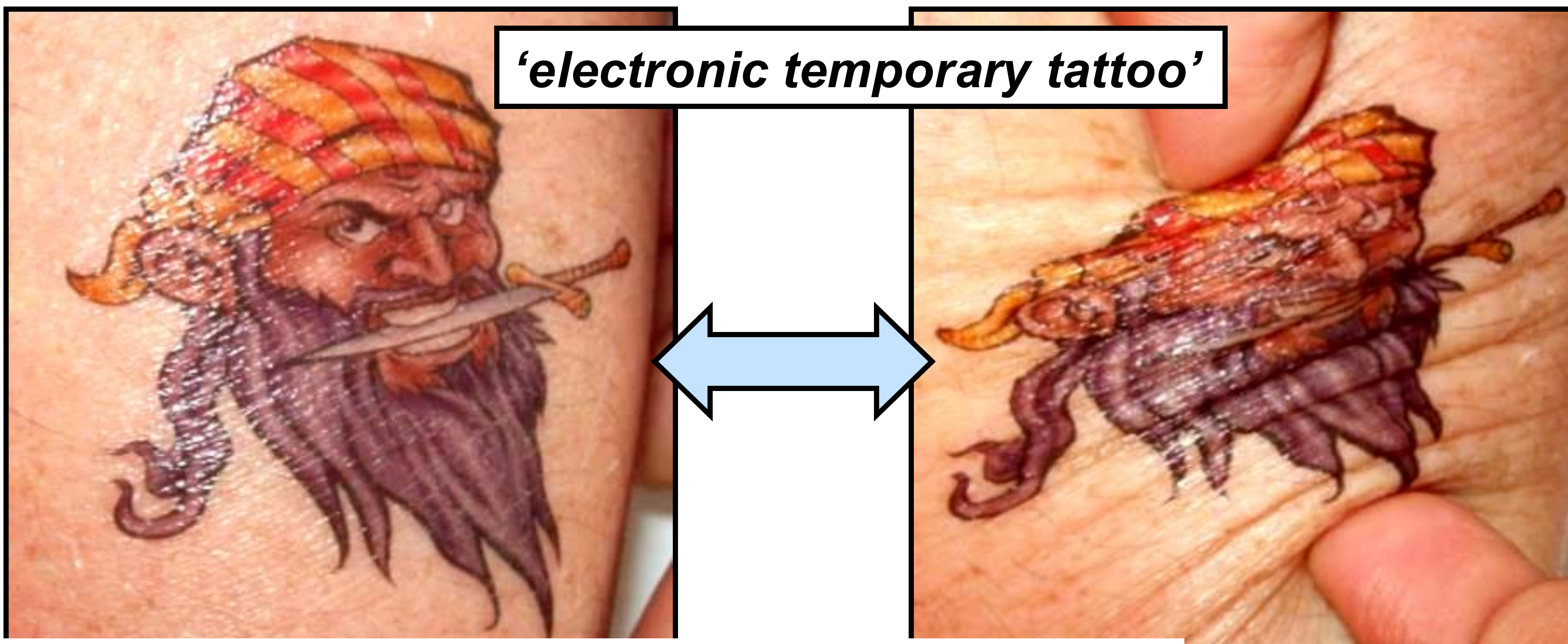
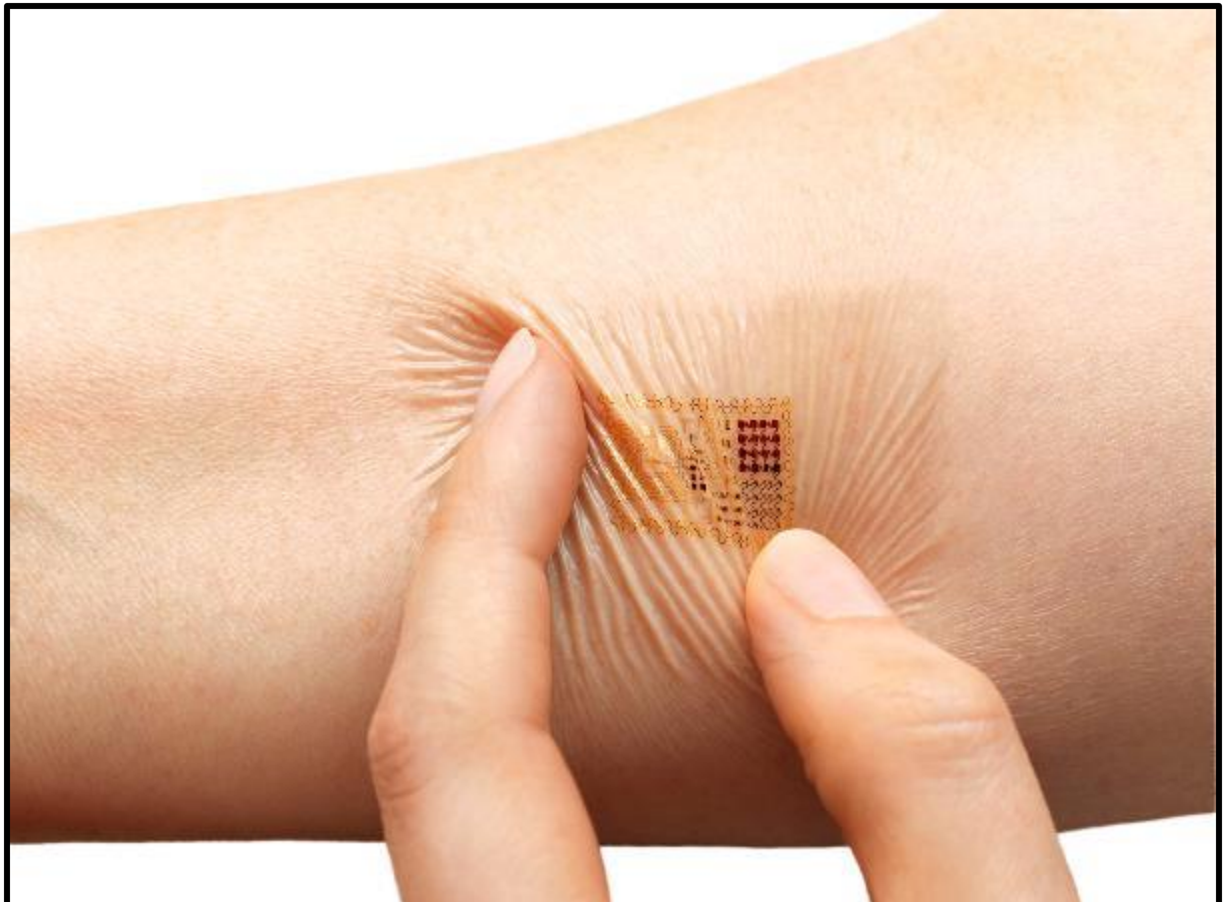
‘Epidermal’ Electronics

1) Ultra-thin (~5 μm), ultra-light (~1 mg/cm^2)
2) Ultra-low modulus (~5 kPa), stretchable (30%)
3) Air/water permeable; waterproof



~2008 / 2009, Rogers et al, DSRC study group report to DARPA

‘Epidermal’ Electronics

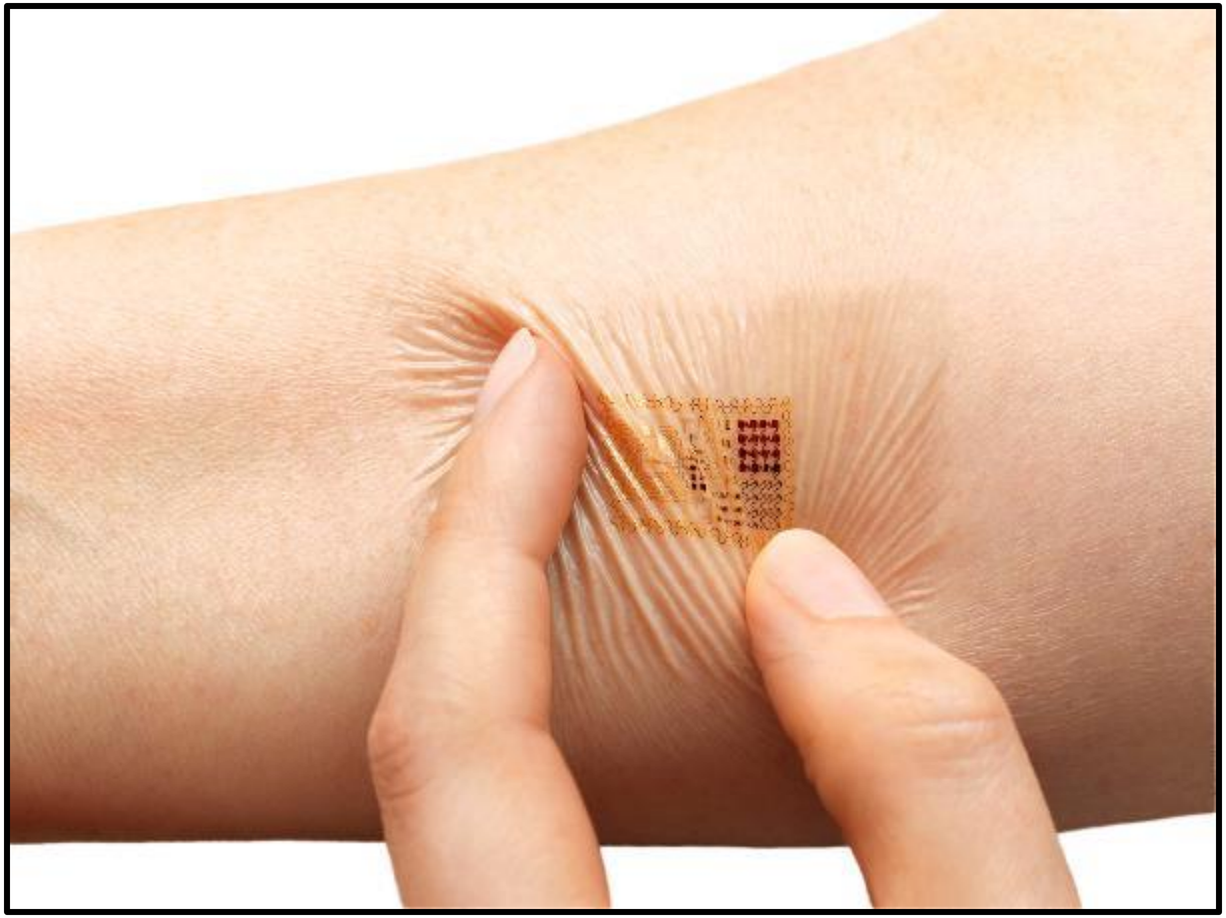


Free Standing

3 mm

Science **333**, 838 (2011).

‘Epidermal’ Electronics



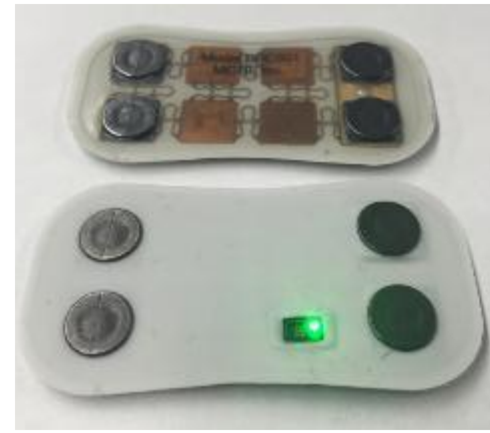
Science **333**, 838 (2011).

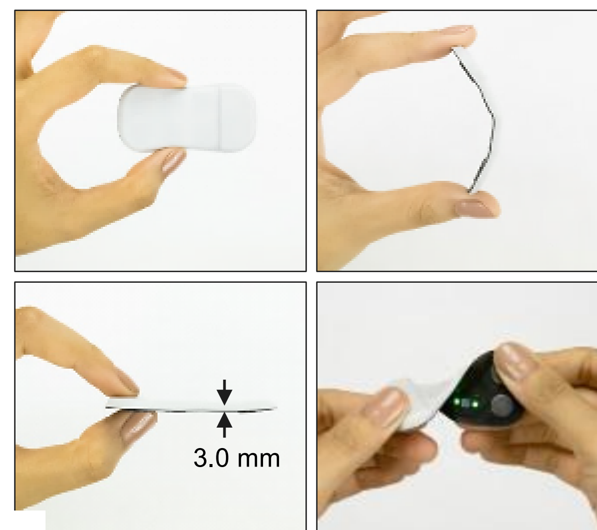
Free Standing

Fitbit Flex 2013

Commercialized ~2012; FDA-Approved in ~2014

1st Stretchable Electronics Product





Acquired in whole by Medidata in 2021

Neonatal Intensive Care

Current **_Future_**

Wireless, Epidermal Vital Signs Monitoring Systems

Science **363**, 6430, eaau0780 (2019).

QUERREY SIMPSON INSTITUTE
FOR BIOELECTRONICS

Engineering & Medicine

45 co-authors

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Mechanical Engineering
Electrical Engineering
Biomedical Engineering
Computer Science
Dermatology
Neonatology
Pediatrics

Graduate students
Undergraduates
Postdocs
Nurses
Doctors
Faculty

RESEARCH ARTICLE SUMMARY

BIOMEDICINE

Binodal, wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care

Ha Uk Chung*, Bong Hoon Kim*, Jong Yoon Lee*, Jungyup Lee*, Zhaoqian Xie*, Erin M. Ibler, KunHyuck Lee, Anthony Banks, Ji Yoon Jeong, Jongwon Kim, Christopher Ogle, Dominic Grande, Yongjoon Yu, Hokyung Jang, Pourya Assem, Dennis Ryu, Jean Won Kwak, Myeong Namkoong, Jun Bin Park, Yechan Lee, Do Hoon Kim, Arin Ryu, Jaeseok Jeong, Kevin You, Bowen Ji, Zhuangjian Liu, Qingze Huo, Xue Feng, Yujun Deng, Yeshou Xu, Kyung-In Jang, Jeonghyun Kim, Yihui Zhang, Roozbeh Ghaffari, Casey M. Rand, Molly Schau, Aaron Hamvas, Debra E. Weese-Mayer, Yonggang Huang, Seung Min Lee, Chi Hwan Lee, Naresh R. Shanbhag, Amy S. Paller†, Shuai Xu†, John A. Rogers†

INTRODUCTION: In neonatal intensive care units (NICUs), continuous monitoring of vital signs is essential, particularly in cases of severe prematurity. Current monitoring platforms require multiple hard-wired, rigid interfaces to a neonate's fragile, underdeveloped skin and, in some cases, invasive lines inserted into their delicate arteries. These platforms and their wired interfaces pose risks for iatrogenic skin injury, create physical barriers for skin-to-skin parental/neonate bonding, and frustrate even basic clinical tasks. Technologies that bypass these limitations and provide additional, advanced physiological monitoring capabilities would directly address an unmet clinical need for a highly vulnerable population.

RATIONALE: It is now possible to fabricate wireless, battery-free vital signs monitoring systems based on ultrathin, "skin-like" measurement modules. These devices can gently and noninvasively interface onto the skin of neonates with gestational ages down to the edge of viability. Four essential advances in engineering science serve as the foundations for this technology: (i) schemes for wireless power transfer, low-noise sensing, and high-speed data communications via a single radio-frequency link with negligible absorption in biological tissues; (ii) efficient algorithms for real-time data analytics, signal processing, and dynamic baseline modulation implemented on the sensor platforms themselves; (iii) strategies for time-synchronized streaming of wireless data from two separate devices; and (iv) designs that enable visual inspection of the skin interface while also allowing magnetic resonance imaging and x-ray imaging of the neonate. The resulting systems can be much smaller in size, lighter in weight, and less traumatic to the skin than any existing alternative.

RESULTS: We report the realization of this class of NICU monitoring technology, embodied as a pair of devices that, when used in a time-synchronized fashion, can reconstruct full vital signs information with clinical-grade precision. One device mounts on the chest to capture electrocardiograms (ECGs); the other rests on the base of the foot to simultaneously record photoplethysmograms (PPGs). This binodal system captures and continuously transmits ECG, PPG, and (from each device) skin temperature data, yielding measurements of heart rate, heart rate variability, respiration rate, blood oxygenation, and pulse arrival time as a surrogate of systolic blood pressure. Successful tests on neonates with gestational ages ranging from 28 weeks to full term demonstrate the full range of functions in two level III NICUs.

The thin, lightweight, low-modulus characteristics of these wireless devices allow for interfaces to the skin mediated by forces that are nearly an order of magnitude smaller than those associated with adhesives used for conventional hardware in the NICU. This reduction greatly lowers the potential for iatrogenic injuries.

CONCLUSION: The advances outlined here serve as the basis for a skin-like technology that not only reproduces capabilities currently provided by invasive, wired systems as the standard of care, but also offers multipoint sensing of temperature and continuous tracking of blood pressure, all with substantially safer device-skin interfaces and compatibility with medical imaging. By eliminating wired connections, these platforms also facilitate therapeutic skin-to-skin contact between neonates and parents, which is known to stabilize vital signs, reduce morbidity, and promote parental bonding. Beyond use in advanced hospital settings, these systems also offer cost-effective capabilities with potential relevance to global health. ■

ON OUR WEBSITE

Read the full article at http://dx.doi.org/10.1126/science.aau0780

Wireless, skin-like systems for vital signs monitoring in neonatal intensive care. (**A**) Images and finite-element modeling results for ECG and PPG devices bent around glass cylinders. (**B**) A neonate with an ECG device on the chest. (**C** and **D**) A mother holding her infant with a PPG device on the foot and an ECG device on the chest (C) and on the back (D).

The list of author affiliations is available in the full article online.
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†Corresponding author. Email: apaller@northwestern.edu (A.S.P.); stevexu@northwestern.edu (S.X.); jrogers@northwestern.edu (J.A.R.)

Cite this article as H. U. Chung et al., Science 363, eaau0780 (2019). DOI: 10.1126/science.aau0780

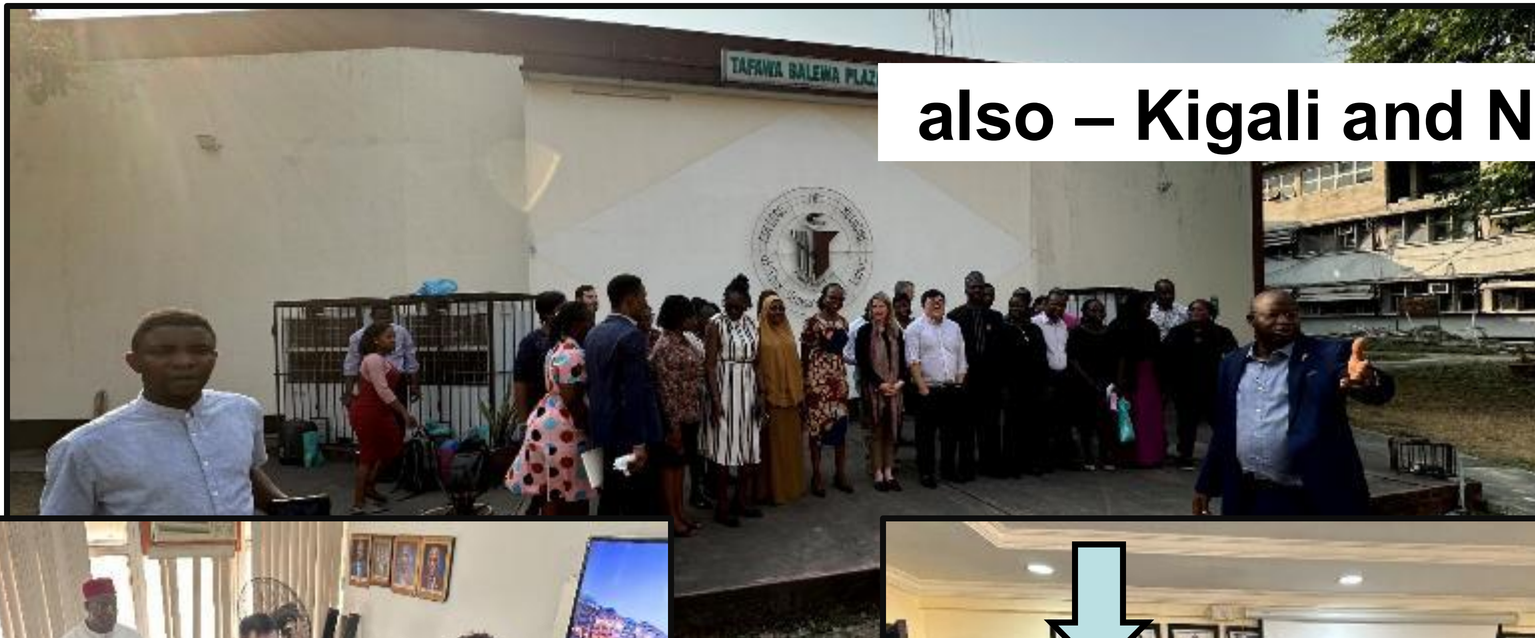
Scaled Deployments into India, Pakistan, Zambia, Kenya and Ghana: 2019-present

BILL & MELINDA GATES foundation

Save the Children®

1st Deployment – Training Session in Zambia (Dec 2019)

On-going Work – Training Session in Lagos (Jan 2025)



also – Kigali and Nairobi

SIBEL

Clinical Translation -- Accomplishments

The Mission

Better Health Data for All®

The Vision

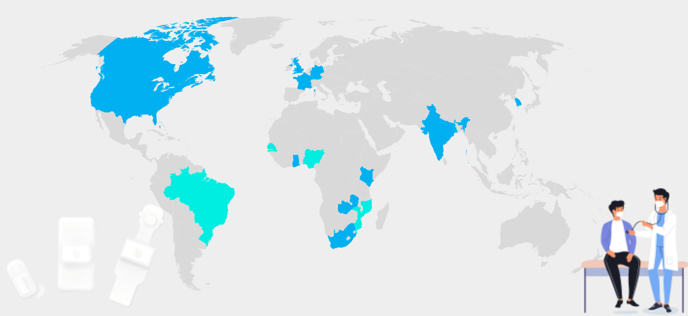
We develop best-in-class medical monitoring solutions from clinical trials to the ICU.

Advanced Medical Monitoring Powering Healthcare AI

anne® one | discovery | anne Care | anne® maternal | anne® pediatric

Breakthrough Clinical Grade Wearables with Integrated AI, Software, and OEM Sensors

Global Scale in 20 Countries



7,000 sensors

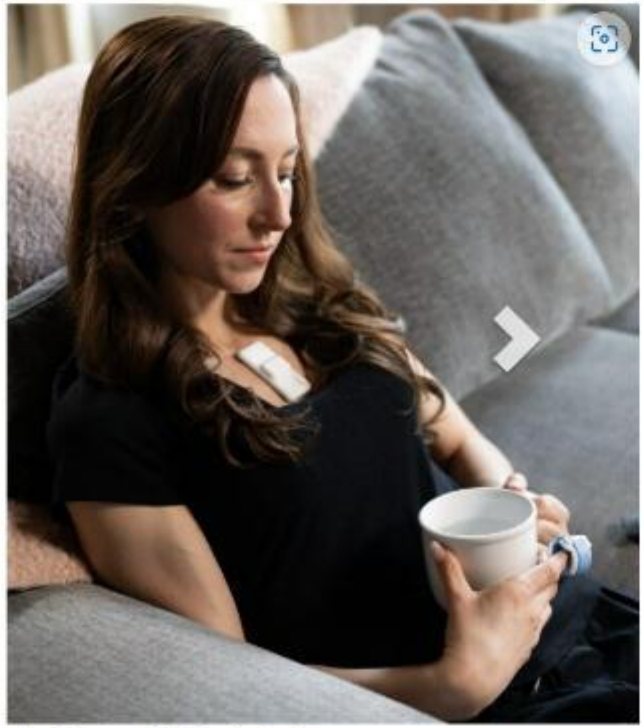
17,000 patients

Enterprise Customers Globally

Dräger
NCH the new children's hospital
Shirley Ryan Abilitylab
Sunnybrook
SPACELABS HEALTHCARE
almirall
McGill University Health Centre
Ann & Robert H. Lurie Children's Hospital of Chicago
Northwestern Medicine
maruho
Bristol Myers Squibb
NHS University Hospitals Birmingham NHS Foundation Trust
Bill & Melinda Gates foundation
University of Waterloo
NHS Lothian
abbvie

Sibel Health and the Capital Region of Denmark

Sibel Health selected by the Capital Region of Denmark to provide continuous wireless monitoring through an innovative collaboration partnership.



ANNE Chest sensor is capable of continuously monitoring multiple vital signs.

Competition:

& others

COPENHAGEN, Denmark and CHICAGO, Dec. 12, 2024 /PRNewswire/ -- The Capital Region of Denmark has selected Sibel Health, an award-winning medical technology company spun out of the Querrey-Simpson Institute for Bioelectronics at Northwestern University, for a long-term innovation partnership along with Dräger to deploy advanced continuous monitoring in the hospital setting after a highly competitive, multi-year global selection process. Sibel Health manufactures the FDA-cleared ANNE® One monitoring platform powered by clinical-grade wearables for all vital signs. For the Capital Region of Denmark, new monitoring technologies are needed to address staffing shortages, an increase in patient load, and the move to single rooms.

Sibel Health - Team

Measurement Capabilities

Thermal: Thermography, Thermal Transport, Hydration

Electrical: Biopotential (ECG, EMG, EEG), Hydration

Fluidic: Sweat (loss and chemistry), blood flow

Mechanical: Strain, motion, modulus, pressure

Optical: UVA/UVB, oximetry, PPG, vein mapping

Mechano-acoustic – cardiac auscultation, etc.

Multimodal, Clinical Quality, Continuous
Low Cost & Available to Everyone

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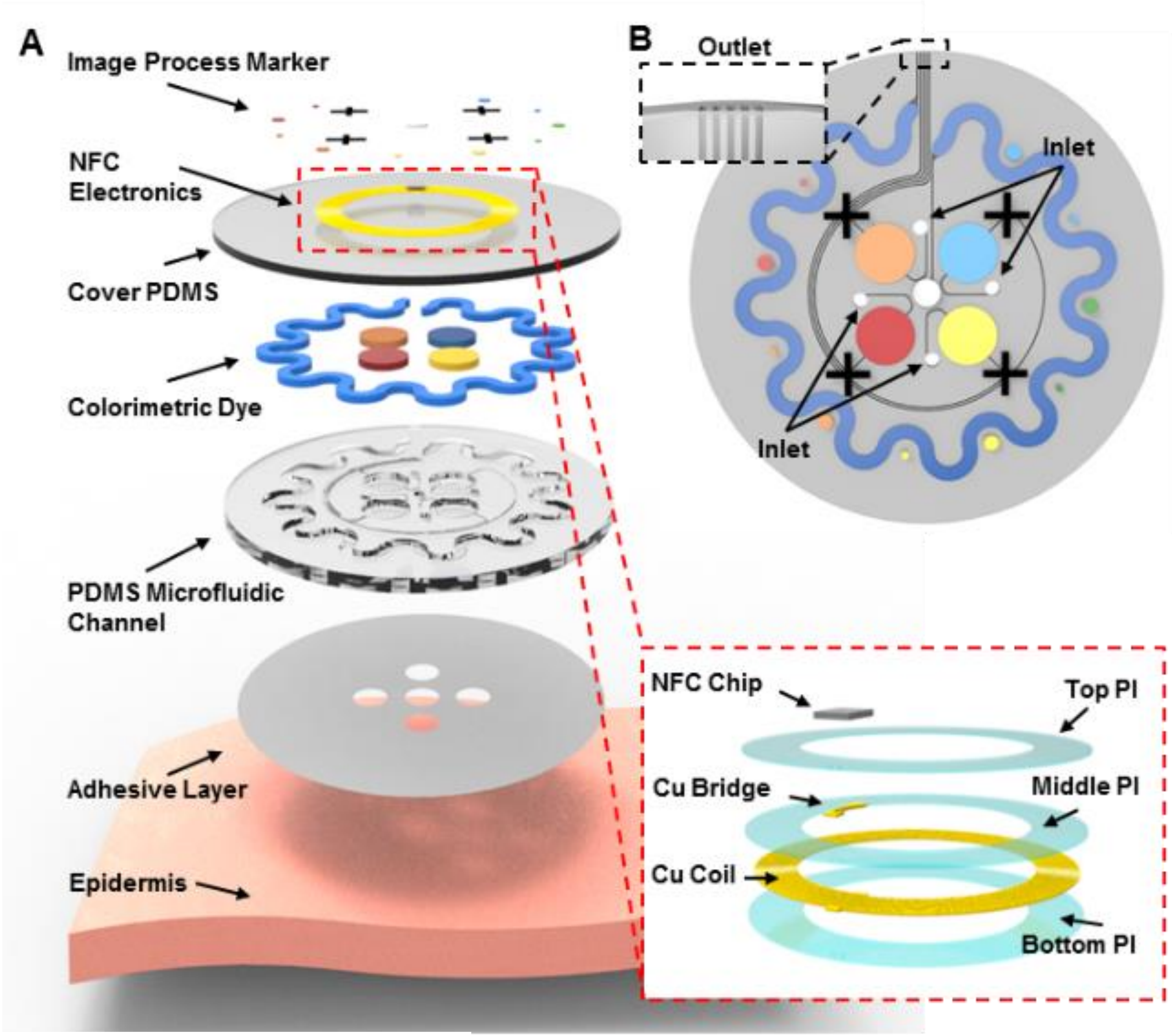
Epidermal Microfluidic Devices and Sweat Analytics



Sci. Transl. Med. **8**, 366ra165 (2016).

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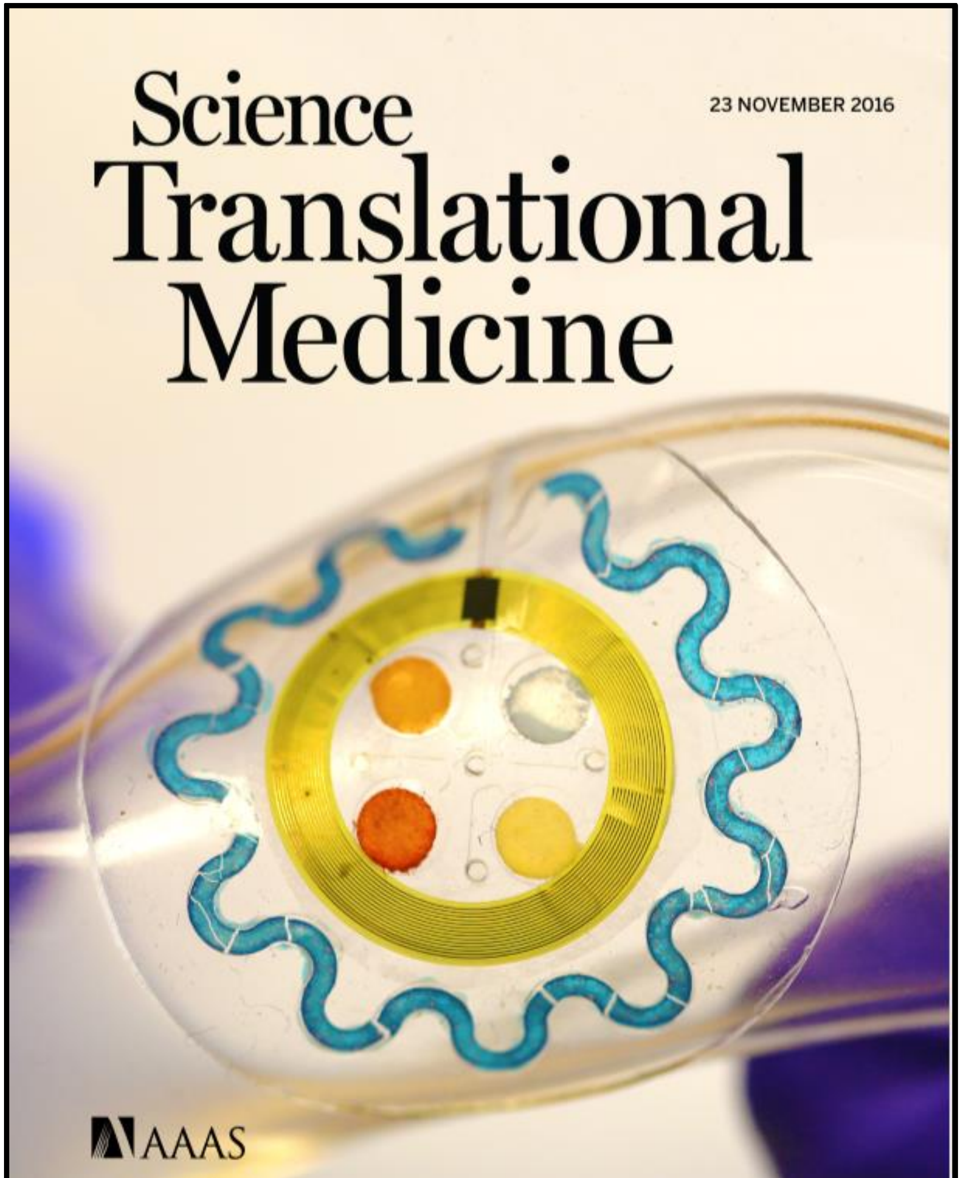


SCIENCE TRANSLATIONAL MEDICINE | RESEARCH ARTICLE

BIOSENSORS

A soft, wearable microfluidic device for the capture, storage, and colorimetric sensing of sweat

Ahyeon Koh,[1*] Daeshik Kang,[1,2*] Yeguang Xue,[3] Seungmin Lee,[1] Rafal M. Pielak,[4] Jeonghyun Kim,[1,5] Taehwan Hwang,[1] Seunghwan Min,[1] Anthony Banks,[1] Philippe Bastien,[6] Megan C. Manco,[7] Liang Wang,[3,8] Kaitlyn R. Ammann,[9] Kyung-In Jang,[1] Phillip Won,[1] Seungyong Han,[1] Roozbeh Ghaffari,[10] Ungyu Paik,[5] Marvin J. Slepian,[9] Guive Balooch,[4] Yonggang Huang,[3] John A. Rogers[1†]

Capabilities in health monitoring enabled by capture and quantitative chemical analysis of sweat could complement, or potentially obviate the need for, approaches based on sporadic assessment of blood samples. Established sweat monitoring technologies use simple fabric swatches and are limited to basic analysis in controlled laboratory or hospital settings. We present a collection of materials and device designs for soft, flexible, and stretchable microfluidic systems, including embodiments that integrate wireless communication electronics, which can intimately and robustly bond to the surface of the skin without chemical and mechanical irritation. This integration defines access points for a small set of sweat glands such that perspiration spontaneously initiates routing of sweat through a microfluidic network and set of reservoirs. Embedded chemical analyses respond in colorimetric fashion to markers such as chloride and hydronium ions, glucose, and lactate. Wireless interfaces to digital image capture hardware serve as a means for quantitation. Human studies demonstrated the functionality of this microfluidic device during fitness cycling in a controlled environment and during long-distance bicycle racing in arid, outdoor conditions. The results include quantitative values for sweat rate, total sweat loss, pH, and concentration of chloride and lactate.

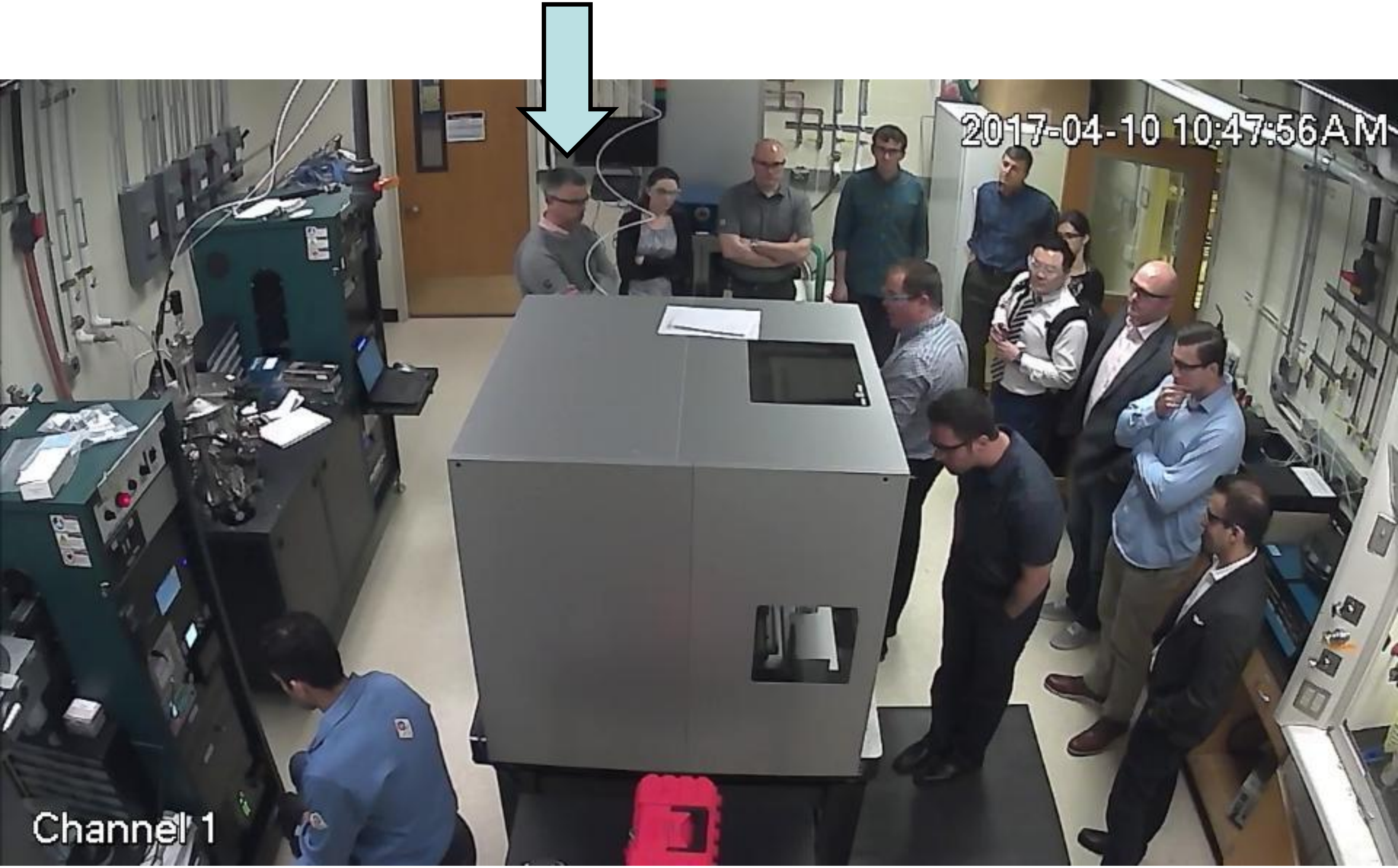
INTRODUCTION

A convergence of advances in materials, mechanics design, and specialized device architectures is beginning to establish the foundations for a next generation of wearable electronic technologies, where sensors and other functional components reside not in conventional rigid packages mounted on straps or bands but instead interface directly on the skin (*1*, *2*). Specifically, devices that combine soft, low-modulus physical properties and thin layouts allow robust, nonirritating, and long-lived interfaces with the human epidermis (*2*). This developing field involves innovative ideas in both organic and inorganic functional materials, where mechanical and manufacturing science play important roles. Although most devices described in the literature focus on measurement of physical characteristics such as motion, strain, stiffness, temperature, thermal conductivity, biopotential, electrical impedance, and related parameters (*1*, *3*–*10*), complementary information—often with high clinical value—could be realized through capture and biochemical analysis of biofluids such as sweat (*11*, *12*).

As a representative biofluid, sweat is of particular interest owing to its relative ease of noninvasive collection and its rich content of important biomarkers including electrolytes, small molecules, and proteins (*13*, *14*). Despite the importance of sweat analysis in biomedicine, interpreting information from sweat can be difficult due to uncertainties in its relationship with other biofluids, such as interstitial fluid and blood, and due to the lack of biomedical appliances for direct sampling and detection of multiple biomarkers without evaporation (*15*). In situ quantitative analysis of sweat is nevertheless of great interest for monitoring of physiologic health status (for example, hydration state) and for the diagnosis of disease (for example, cystic fibrosis) (*16*, *17*). Existing systems for whole-body sweat collection have been confined to the laboratory (*18*), where standard chemical analysis technologies (chromatography, mass spectroscopy, and electrochemical detection) can reveal the composition of collected samples (*19*). Recent attempts to detect and collect sweat simultaneously involve direct contact with sensors on the skin (for example, temporary tattoo) where fabric or paper substrates accumulate sweat for electrochemical and/or optical assessment (*20*). For instance, electrochemical sensors directly laminated on the epidermis can detect chemical components, such as sodium ions and lactate, in real time (*21*–*23*). Colorimetric responses in functionalized porous substrates can yield chemical information, such as the pH of sweat, and further enable simple quantitative assays using devices capable of capturing high-quality digital images, such as smartphones (*24*–*26*). Radio frequency identification systems, which can be integrated on top of porous materials for wireless information transfer, provide additional functionality (*27*, *28*). These and related technologies can quantify sweat generation rate (*27*), but because the sweat gland density and overall areas are typically unknown, the total sweat rate and volumetric loss cannot be determined accurately. In addition, the most widely explored formats do not simultaneously reveal the concentration of multiple chemical components, nor do they offer full compatibility with the growing availability of soft, skin-mounted electronics, physical sensors, radio technologies, and energy storage devices.

[1]Department of Materials Science and Engineering, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA. [2]Department of Mechanical Engineering, Ajou University, Suwon 443-749, Korea. [3]Departments of Civil and Environmental Engineering, Mechanical Engineering, and Materials Science and Engineering, Northwestern University, Evanston, IL 60208, USA. [4]L'Oréal Technology Incubator, San Francisco, CA 94107, USA. [5]Department of Energy Engineering, Hanyang University, Seoul 133-791, Korea. [6]L'Oréal Research and Innovation, Aulnay-sous-Bois, France. [7]L'Oréal Early Clinical, Clark, NJ 07066, USA. [8]Department of Chemical and Biological Engineering, Institute of Chemical Machinery and Process Equipment, Zhejiang University, Hangzhou 310027, People's Republic of China. [9]Department of Medicine and Biomedical Engineering, Sarver Heart Center, University of Arizona, Tucson, AZ 85724, USA. [10]MC10 Inc., Cambridge, MA 02140, USA.
*These authors contributed equally to this work.
†Corresponding author. Email: jrogers@illinois.edu

President of Gatorade (Brett O'Brien)




EPICORE
BIOSYSTEMS

Colorimetric Chloride Detection

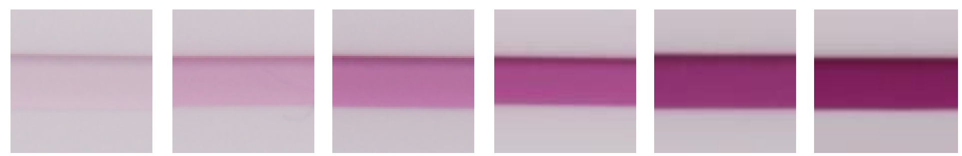
Chloride Assay

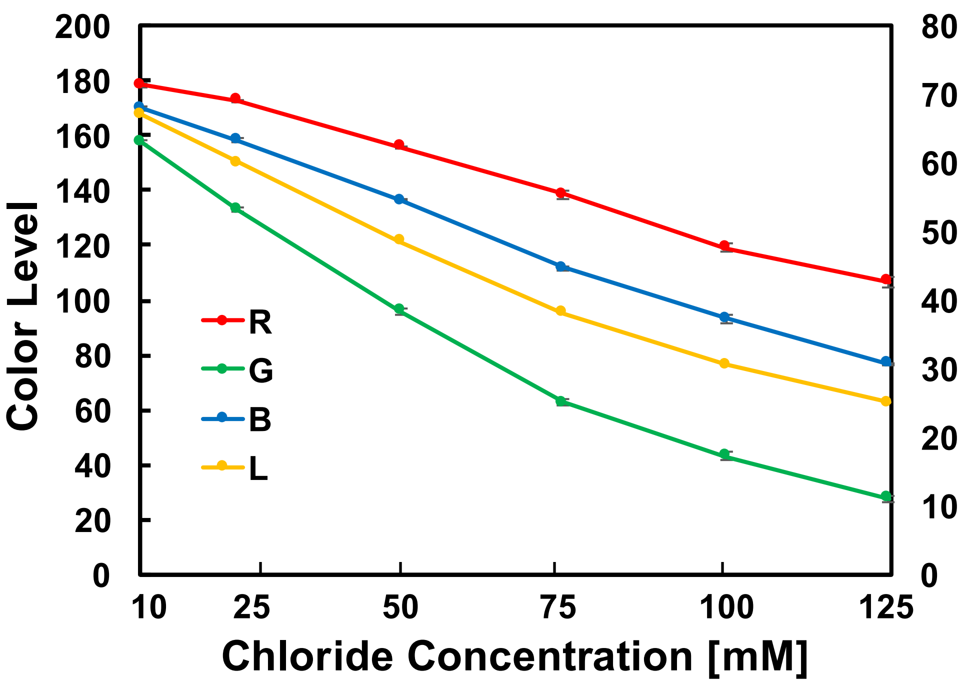
Chloride in sweat

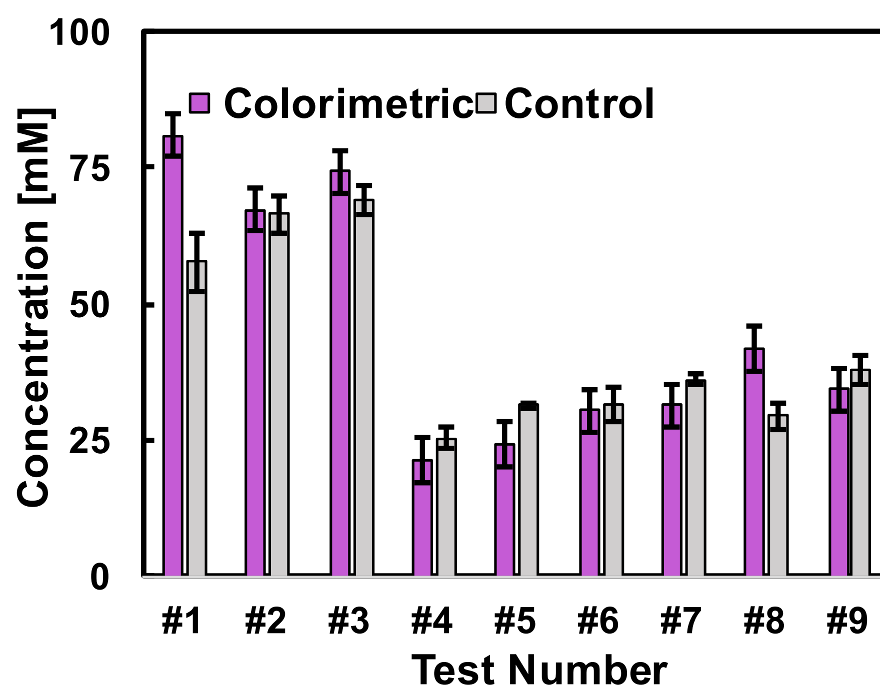
$$C_6Ag_2Cl_2O_4 + 4Cl^- + H^+ \rightarrow 2AgCl_2(s) + HC_6Cl_2O_4^- \text{ (purple ion)}$$

Silver Chloranilate | precipitation | Acid chloranilate ion

Chloride Concentration [mM]: 10, 25, 50, 75, 100, 125







Gatorade | You Fuel Us, We Fuel You ft. S. Williams, J. Tatum, C. Pulisic, L. Sanders

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Gatorade
Published on Dec 21, 2018

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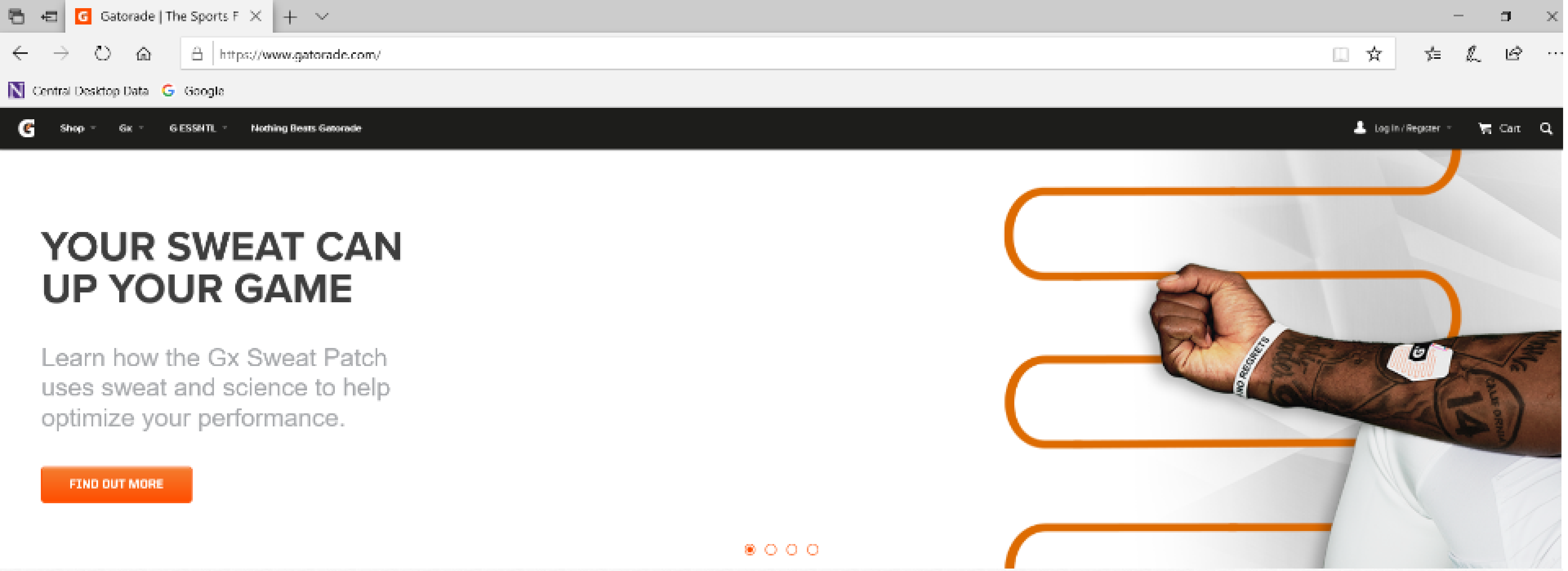
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Learn how the Gx Sweat Patch uses sweat and science to help optimize your performance.
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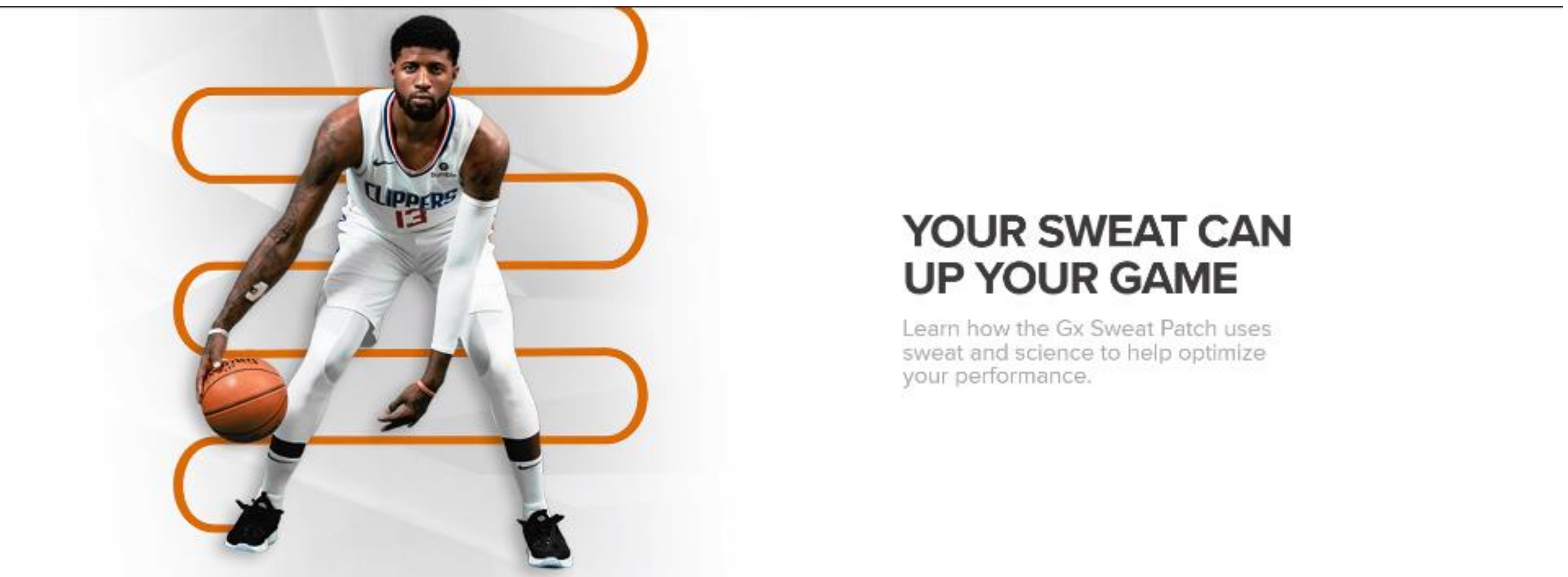
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13
YOUR SWEAT CAN UP YOUR GAME
Learn how the Gx Sweat Patch uses sweat and science to help optimize your performance.

GATORADE Gx SYSTEM

Gatorade Gx is a holistic sports fuel customization platform that combines cutting-edge science with newly designed equipment and tracking technologies to provide fueling recommendations specific to individuals. This innovative platform will change the way athletes of all levels hydrate now and into the future.

Working in harmony, the sweat patch, water bottle, and app, help athletes to prepare, workout, and repair. We leveraged a design thinking process to understand what athletes want from their tools. This innovative approach provided a 360° comprehensive platform that truly understands the human body. We also offer a digital weigh-in station, an influencer app, and a smart cap to ensure access to everything one could need for optimum performance.

In 2022, Gx drove **$90MM** in sales, a +63% year on year growth rate versus 2021.

The Gx bottle is the best-selling item at key sporting goods retailers.

Gatorade Gx has driven over **500MM** views on TikTok, with #Gatorade achieving a total of **2.6B** views on the platform.

2.6B VIEWS #GATORADE ON TIK TOK

$90MM 2022 SALES

500MM GX VIEWS ON TIK TOK

63% GROWTH RATE

DOUBLED FEMALE AUDIENCE SHARE

HYPEBEAST engadget CNET FAST COMPANY The Drum

EPICORE BIOSYSTEMS

Hydration for Worker Safety – the 'Industrial Athlete'

w/ Chevron and Fluor

EPICORE BIOSYSTEMS

Oil & Gas	Chevron, OXY, ExxonMobil, slb
Construction	BECHTEL, PKS Kiewit, Jacobs, NEOM نيوم
Manufacturing	Chevron Phillips Chemical Company LLC, DOW, Denka, Honeywell, okabe, Calbee
Transportation & Logistics	UNITED AIRLINES, MITSUI-SOKO, NISSIN 日新, UTOC CORPORATION, DFW
Other	Mets, ALLIANCE Safety Equipment, Berkeley University of California, HARVARD, BHP, NUS National University of Singapore, Minnesota Twins, AES, BAYER

Epicore Biosystems - Team

Academic Research → Commercial Translation

Breakthrough science and engineering

High impact proof of concept and validation

Strong IP protection

Deployment and commercialization

Academic Research → Commercial Translation

High impact proof of concept and validation

Strong IP protection

GAP

Deployment and commercialization

Academic Research → Commercial Translation

n=3-5

Breakthrough science and engineering

n=5-20

High impact proof of concept and validation

Strong IP protection

n=50-500

Clinical deployment, health insights, data analytics

Strong IP protection

n>1M

Deployment and commercialization

Northwestern

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FOR **TRANSLATIONAL ENGINEERING**
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