SCIENCE AND CULTURE

Wearable tech meets tattoo art in a bid to revolutionize both

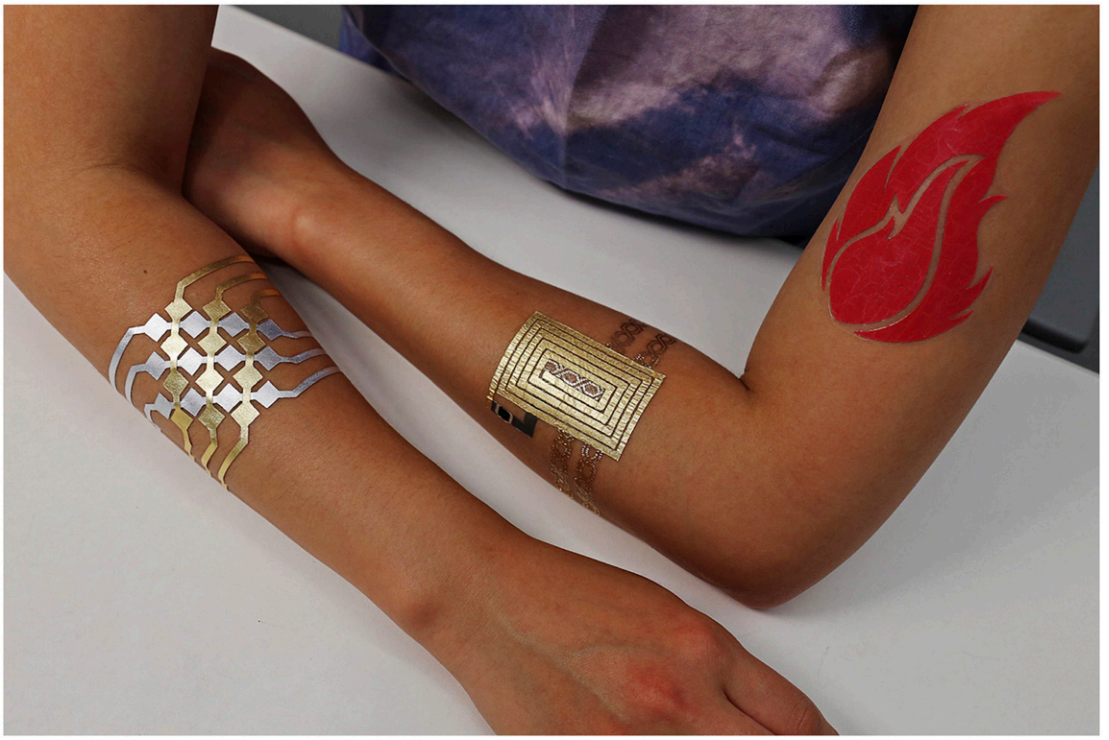
Carolyn Beans, *Science Writer*

Engineer and artist Cindy Hsin-Liu Kao was browsing through *Vogue* a few years ago when an article about temporary metallic-colored tattoos caught her eye. Staring at the glittering shapes that wrapped like jewelry around a model's wrist, Kao wondered if they were conductive. She envisioned the possibilities: on-skin user interfaces that worked as a touch pad, displayed information, or even stored and transmitted data.

It turns out the tattoos weren't conductive. But with the help of colleagues at MIT and Microsoft Research, Kao, an MIT Media Lab PhD candidate, created some that were. The resulting innovation, DuoSkin, is a publicly available fabrication process that enables anyone with access to a craft store, graphic design software, and inexpensive electronics to create gold-leaf temporary tattoos with myriad functions—from advancing songs on a music player to changing color with body temperature (1). At New York Fashion Week in 2017, models donned DuoSkin tattoos that transmitted information about the garments to audience members' smart phones.

Tattoos, both temporary and permanent, have mass appeal. According to a 2010 Pew Research Center report, nearly 40% of millennials have at least one permanent tattoo (2). Like Kao, a growing number of researchers are responding to this trend by creating wearable technologies in the form of temporary and even permanent tattoos.

The tattoos now in development carry real practical and medical import, from doubling as electronics to



Inspired by the trend of metallic tattoo art, the researchers behind DuoSkin designed a process for making gold-leaf temporary tattoos that can function like a track pad, communicate information wirelessly, or change color with body temperature. Image courtesy of Jimmy Day/MIT Media Lab.

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harvesting health information. But researchers agree that to gain widespread use the tattoos must also visually impress. "You have to consider aesthetics," says Kao. "Anything on the body is such an integral part of our identity."

Skin-Like Electronics

Many trace the field of smart tattoos to 2011 when materials researcher and bioengineer John Rogers, now of Northwestern University, described his "epidermal electronic system" in *Science* (3). His team packed electrodes, electronics, sensors, power supplies, and communications components into a stretchable, ultrathin, silicone-based membrane that sticks to skin much like a temporary tattoo.

Rogers, who cofounded MC10, Inc., a company that develops wearables for healthcare data collection, demonstrated possible applications, including measuring activity in the brain (EEG), heart (ECG), and muscle (EMG). Because the tattoos transmit data wirelessly and without adhesive tapes, straps, and conductive gels, the device could enable patients, athletes, or anyone interested in his own vital signs to monitor himself outside of a medical setting. Rogers' company has already released a version of this product called BioStamp, which helps researchers track study subjects and doctors follow patient health. The battery required for the current product, however, makes the device thicker than a temporary tattoo.

Rogers also collaborated with L'Oréal to create a UV-detecting device that doesn't rely on a battery and functions more like a temporary tattoo. Released in 2016, the heart-shaped "My UV Patch" contains photosensitive dyes that change color with the accumulation of UV rays. "Because it's a visually observable color change, you can certainly get a pretty good idea of UV exposure just by looking at it," says Rogers. Wearers can also photograph the tattoo via a mobile app that analyzes the color change and reports the level of cumulative UV exposure.

And that's not the only UV tattoo in the works. Researchers at a San Francisco-based start-up company called LogicInk are working on a temporary tattoo that indicates cumulative UV exposure with an outer ring and current UV levels with an inner one. The wearer can use a smartphone to log daily exposure. But the basic question of whether to stay in the sun or find shade can be answered just by glancing at the tattoo, says Carlos Olguin, a LogicInk cofounder. The team wants to create these tattoos without any internal electronics or the need for a smartphone readout.

Many of the tattoos in development share a common aim: mining the body for data. MIT materials researcher Xuanhe Zhao recently created a proof-of-concept "living tattoo" that uses bacteria that are printed in the shape of a tree within a flexible hydrogel material and light up in response to chemical compounds on human skin (4). The team envisions one day incorporating bacteria engineered to respond to a range of stimuli, from environmental chemicals and pollutants to changes in pH and temperature.

The soon-to-be-released LogicInk UV tattoo will indicate cumulative UV exposure with an outer ring and current UV levels with an inner one. Image courtesy of LogicInk Corporation.

Meanwhile, at the University of California San Diego, nanoengineer Joseph Wang and colleagues developed another proof-of-concept temporary tattoo that measures glucose levels, a possible needle-free alternative for diabetics (5).

And mechanical and materials engineer Nanshu Lu of the University of Texas at Austin, a colead author on Rogers' seminal paper, recently developed a graphene tattoo that measures vital signs. "No one would be able to see it unless you look very closely," she says (6). For those who want to make a fashion statement, she has a showier gold- and titanium-based version that she's commercializing through her startup, Rotex. In hopes of someday helping people whose medical conditions require constant monitoring, Katia Vega, a beauty-tech designer, then a postdoctoral fellow at the MIT Media Lab, began developing Dermal Abyss, a permanent smart tattoo, with collaborators in her group and at Harvard Medical School. After learning from tattoo artists how to use a tattoo machine, Vega swapped traditional inks for biosensors whose colors change to report sodium, glucose, and pH levels in the interstitial fluid of the skin. She tested the idea in skin extracted from a pig (7).

Making it to Market

With the exception of DuoSkin's do-it-yourself tattoo-making instructions and L'Oreal and LogicInk's UV detectors, most projects haven't made it onto (or into) the skin of the general public. "It's coming," says Rogers. "A lot of companies are working in this space. It just takes time because you can't just run off and call up your local electronics manufacturer and tell them you want skin-like devices."

If Vega were to move forward with Dermal Abyss, she foresees plenty of necessary improvements; she would have to, for example, test the biosensors for

toxicity. Wang says that before his team's product gains approval from the US Food and Drug Administration, they'll have to demonstrate results that match those from traditional needle-based glucose testing, regardless of skin roughness or permeability.

Likewise, before LogicInk can commercialize a tattoo that includes a small-molecule sensor for detecting ethanol levels in sweat—a device that won an honorable mention in the 2016 National Institute on Alcohol Abuse and Alcoholism's Wearable Alcohol Biosensor Challenge—the company must determine that it works consistently. One challenge: The ethanol signal from a person who sweats less may be difficult to amplify enough such that it changes the tattoo's color.

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>
> —Carlos Olguin

Lu expects it'll be 5 years or more before her graphene tattoo reaches the public. "Something this soft and thin is very fragile," she says. "Although we have prototypes that work, if you want to talk about a very reliable, resilient, robust product, there is still a long way to go."

When smart tattoos do make it to market, many researchers predict consumers will be ready. Vega says that she's received hundreds of emails from people wanting to try Dermal Abyss. And Kao is thrilled to see people designing tattoos using her process, including an elementary school class that made a tattoo that, when tapped, takes selfies.

Artistic Touch

Are these innovations simply new technologies, a genuine evolution of tattoo art, or both? Rogers doesn't consider himself an artist, but he's learned to pay attention to design. "The visual appearance, the colors, the patterns are absolutely critical to getting people excited," he says. Curators at the Museum of Modern Art in New York included his "Lab on the Skin" tattoo-like device in the exhibit "Items: Is Fashion Modern?" which ran through January 28, 2018. The device uses color-responsive chemical reagents to analyze a person's sweat. Its streamlined appearance shows four colored dots reporting pH, lactate, chloride, and glucose levels encircled by a wavy line that reports sweat loss, all embedded in a clear circle (8).

Aesthetics also played a role in the development of the LogicInk UV tattoo, which is set to hit the market in 2018. "We're trying to ride this cultural conversation going on around the usage of tattoos," says Olguin. "We're trying to be a conduit of health awareness but also self-expression."

E Roon Kang, LogicInk's tattoo's designer, met weekly with the research team as he explored different approaches for tackling the challenge of combining readability with scientific accuracy and aesthetic appeal. "It's a piece of graphic. It's something that you wear. But at the same time, it's an interface, a visualization of information," he says. The manufacturing process presented some limitations. The team applies the pigment much like silk screening, which works best with large blocks of color. Incorporating a photographic image, says Kang, is "just out of the question."

Tattoo historian Anna Felicity Friedman, author of *The World Atlas of Tattoo*, says that only the Dermal Abyss project might be considered tattooing; most tattoo enthusiasts classify temporary tattoos as something altogether separate. Sociologist David Lane of the University of South Dakota, who is writing an ethnography about tattoo workers in Baltimore, agrees. "It would be cool to have a little touch pad on my arm," he says. "But it's not a tattoo in my mind."

Kao, though, sees a direct connection between traditional tattooing and the smart tattoos she and others are developing. "I think it's a really innate human desire to decorate our bodies," she says. "In the past, we've been using pigments, the materials around us. Now, because technology is evolving to become so miniature and materials are so flexible and malleable, it only makes sense to use technology to decorate our bodies. It's exciting to be at this place and time where we can start doing that."

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3 Kim D-H, et al. (2011) Epidermal electronics. *Science* 333:838–843.

4 Liu X, et al. (2018) 3D printing of living responsive materials and devices. *Adv Mater* 30:1704821.

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