EPIDERMAL ELECTRONICS

Skin health monitoring

Ultrathin and conformal piezoelectric transducers enable high-resolution mapping of the mechanical properties of human skin.

Stéphanie P. Lacour

Our skin reveals many aspects of our overall health, ethnicity, age, and social and physical environment. Its mechanical properties are often tested by practitioners as a first gauge of our status; for instance, applying light pressure with a finger on the skin can be used to give an indication of circulatory function, and a gentle pinch can provide information on the skin stiffness and hydration. But these procedures and their outcome strongly depend on the practitioner and their experience[1,2]. Also, cutaneous pathologies may be recognized by the changes they induce in the skin elasticity, but this metric is challenging to measure reliably without invasive procedures such as a biopsy. A potential solution to these issues is now proposed by John Rogers and colleagues, who report in *Nature Materials* a bioelectronic adhesive bandage that performs on-skin monitoring and mapping of the viscoelasticity of the skin with a spatial resolution unmatched so far[3].

The smart bandage emanates from the long experience of the authors in designing and manufacturing ultrathin and conformal electronic transducers, a technology referred to as epidermal electronics[4,5]. Briefly, inorganic thin-film devices are turned from rigid and brittle to flexible and conformable to soft biological tissues by making them as thin as possible. These devices are then embedded in micrometre-thick plastic films, which are further patterned in a meandering two-dimensional mesh and supported by a thin elastomer adhesive (Fig. 1a). The epidermal electronic circuit sticks to the biological tissue by van der Waals forces alone, and may be removed and reapplied many times.

The conformal modulus sensor demonstrated here hosts a linear array of alternating piezoelectric sensors and actuators prepared with nanoribbons of lead zirconate titanate (PZT). Small oscillations generated by a given PZT actuator are mechanically coupled through the biological tissue and the supporting adhesive to the neighbouring PZT sensors. Output voltages of the sensor are directly proportional to the elastic modulus of the biological tissue, offering a straightforward and non-invasive method to quantify the mechanical metric.

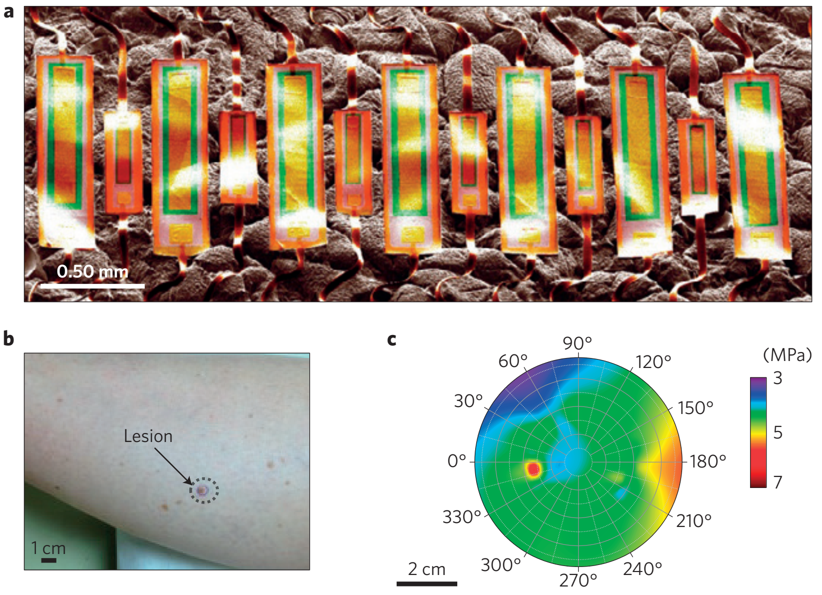

Figure 1 | Ultrathin and conformal piezoelectric transducing bandage. **a**, False-coloured scanning electron microscopy image of an array of alternating piezoelectric actuators and sensors laminated on an artificial skin sample. **b**, Image of a patient's leg with a skin lesion. **c**, Spatial mapping of the elasticity of the skin close to the lesion acquired with the soft bioelectronic bandage, showing that the stiffness increases at the site of the lesion. Figure reproduced from ref. 3, Nature Publishing Group.

Rogers and colleagues successfully implemented the bioelectronic bandage to monitor skin stiffness *in vivo* across a diverse cohort of patients, and revealed specific changes in skin properties as a function of gender, age, body location, skin treatment and lesions. Applied to the skin of a patient with cancer, the device mapped with millimetre resolution the regional stiffness of the skin and revealed localized changes in elasticity near lesion sites (Fig. 1b,c). Importantly, the smart wearable sensor was readily accepted by the patients, highlighting the comfort and imperceptible nature of the non-invasive bioelectronic device. The possibility to perform such systematic clinical trials can help in deciphering the mechanics of skin and developing new therapies in dermatology and, in particular, in skin cancer research. In fact, the incidence of melanomas has been increasing over the past decades, with an alarming number of one in three cancers diagnosed being a skin cancer[6]. Hence, there is a great need to bring accurate monitoring devices to dermatologists and ultimately to patients to evaluate skin lesions and to monitor the benefits of a specific treatment.

The researchers also demonstrated the relevance of these devices in cosmetic research. Taking advantage of the ultrathin piezoelectric transducers, they directly monitored the effects of moisturizing agents on *ex vivo* samples of skin. The results highlighted the relative increase in elasticity and hydration of the upper layer of the skin along with the temporal effect of the moisturizing agents. Accurate measure of the levels of skin hydration and elasticity promises the design of new cosmetic products better adapted to the ageing effects on skin.

Furthermore, Rogers and colleagues showed that the ultrathin bioelectronic bandage can reliably measure the stiffness of freshly explanted organs. It is common practice for surgeons to use palpation to inspect the surgically exposed tissues and to identify abnormalities and hidden pathological lesions such as tumours. Building on the initial results of Rogers and colleagues, it is possible to envision future endoscopes or catheters embedding palpation probes that detect aberrant lesions with fine spatial resolution, and in a minimally invasive procedure.

Soft bioelectronics, broadly defined as microfabricated devices distributed over large areas and with mechanical properties that match biological tissues[7–10], is an imperative engineering and technological step towards the deployment of diagnostic and therapeutic devices on or in the body. Besides the advanced epidermal electronic system, Rogers and colleagues also demonstrate that integration of expertise from both engineering and biological disciplines is paramount to design, produce and implement the next generation of biomedical and biotechnological devices. This indeed paves the way to engineer new tools for personalized medicine. ❐

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MATERIAL WITNESS

THE COMPLEX COSTS OF FAKING IT

PHILIP BALL

Debates about distinctions between 'natural' and 'synthetic' materials date back to antiquity, when Plato and Aristotle wondered if human 'art' can rival that of nature. Scepticism about alchemists' claims to make gold in the Middle Ages weren't so much about whether their gold was 'real' but whether it could compare in quality to natural gold. Such questions persisted into the modern age, for example in painters' initial suspicions of synthetic ultramarine and in current consumer confusion over the integrity of synthesized natural products such as vitamin C.

It is all too easy for materials technologists to overlook the fact that what to them seems like a question of chemical identity is for users often as much a matter of symbolism. Luxury materials become such because of their cost, not their composition, while attitudes to the synthetic/natural distinction are hostage to changing fashions and values. The market for fake fur expanded in the 1970s as a result of a greater awareness of animal conservation and cruelty, but providing a synthetic alternative was not without complications and controversy. Some animal-rights groups argue that even fakes perpetuate an aesthetic that feeds the real-fur market, while recently there has been a rise in real fur being passed off as faux — a striking inversion of values — to capture the market of 'ethical' fur fans. The moral — familiar to marketeers and economists if less so to materials scientists — is that market forces are dictated by much more than chemical composition.

These considerations resonate strongly in the current debate over plans by Seattle-based bioengineering company Pembient to use 3D printing for making fake rhinoceros horn from keratin. The company hopes to reduce rhino poaching by providing a synthetic alternative that, by some accounts, is virtually indistinguishable in composition, appearance and smell from the real thing. It claims that 45% of rhino horn traders have said they would buy the substitute. How to interpret that figure, even taken at face value, is unclear: will it help save the rhino, or does it show that over half of the buyers value something more than material identity? In the black-market Chinese and Vietnamese medicines that use the horn, it is supposed to imbue the drugs with an essence of the wild animal's vitality: it is not just an ingredient in the same sense as egg is a part of cake mix, but imparts potency and status.

The same is true of the tiger bone traded illegally for medicines and wine. Even providing the real thing in a way that purports to curb the threat to wildlife, as for example when tigers are farmed in China to supposedly relieve the pressure on wild populations, can backfire in the marketplace: some experts say that tiger farming has revitalized what was a waning demand.

Critics of Pembient's plans — the company intends to print tiger bone too — make similar complaints, saying that the objective should be to change the culture that creates a demand for these products rather than pandering to it. There's surely a risk here of unintended outcomes in manipulating markets, but also a need to remember that materials, when they enter culture, become more than what they're made of. ❐