Soft electronics

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A sutureless bioelectronic patch for electrocardiography

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An adhesive bioelectronic patch that can conform to irregular curvilinear surfaces can be used in vivo to stimulate the heart and record electrocardiograms of freely moving rats.

Soft bioelectronics can potentially be used to seamlessly record physiological signals and stimulate electrical impulses through direct physical and electrical interfacing with biological tissue. One key advantage of the technology is that it reduces the mechanical mismatch between the bioelectronic devices and the target tissue, creating stable and intimate electrical coupling[1]. Ideally, soft bioelectronics should be tissue-conformable and adaptive, and thus able to effectively respond to any movement of the biological tissue[2,3]. Fatigue resistance is also important to sustain long-term functionality and provide reliability and longevity for continuous use[4]. Finally, the bioelectronic devices should be able to attach reliably to various organs and biological sites.

Adhesive hydrogels have emerged as an effective material for attaching soft bioelectronics to tissue without the need for suturing[5], which can damage the tissue. However, adhesive bioelectronics have been mostly limited to rodent models, owing to the challenges in achieving instantaneous tissue bonding uniformly over large surface areas. Writing in *Nature Electronics*, Mikyung Shin, Donghee Son and colleagues now report an adhesive soft bioelectronic system for cardiac monitoring that can conform to the complex anatomical features of heart tissue and can achieve instantaneous adhesion without causing damage[6].

The researchers — who are based at Sungkyunkwan University, the Institute for Basic Science and the Korea Institute of Science and Technology — developed a strain-adaptive fibre-interlocked bioelectronic patch (Fig. 1). It consists of multiple layers that each serve a specific purpose for the patch's performance: an ionically conductive tissue adhesive layer, a self-healing fibre-interlocked polymer network layer, and a conductive composite film of polymer and liquid metal. The adhesive layer is based on a catechol-conjugated alginate hydrogel, which provides strong and instantaneous bonding with biological tissues and without requiring additional stimuli, such as pressure.

The fibre-interlocked polymer network layer makes the patch conformable and mechanically durable, allowing it to maintain intimate contact with irregular three-dimensional surfaces. When attached to a curved surface it showed fewer air gaps than a conventional solid film of the same thickness (200 μm). The fibrous structure also exhibits a higher fracture energy (10.3 kJ m^{-2}) than the solid film (5.8 kJ m^{-2}). When the adhesive hydrogel is layered on the fibre-interlocked polymer, its adhesive strength against shear stress increases to 7.2 kPa compared with when on a solid film (4.5 kPa), owing to the efficient strain energy dissipation. The hydrogel with the fibre-interlocked polymer layer can be stretched by 660% strain without noticeable adhesive failure and for 500 stretch–release cycles of 30% strain.

The researchers used a conductive nano-/micro-composite consisting of eutectic gallium indium particles[7] mixed with a self-healable polymer to create fatigue-resistant interconnects. The composite creates an electrical pathway through the formation of coordination bonds between either the Ga^{3+} or In^{3+} ions in the oxide skin of eutectic gallium indium and the adhesive hydrogel. This led to larger and more stable charge injection when compared with the eutectic gallium indium composite alone.

With the multilayered adhesive soft bioelectronic patch, the team achieved a high level of conformability when attached to dynamic tissues. The patch adhered for a period of 60 seconds without slippage

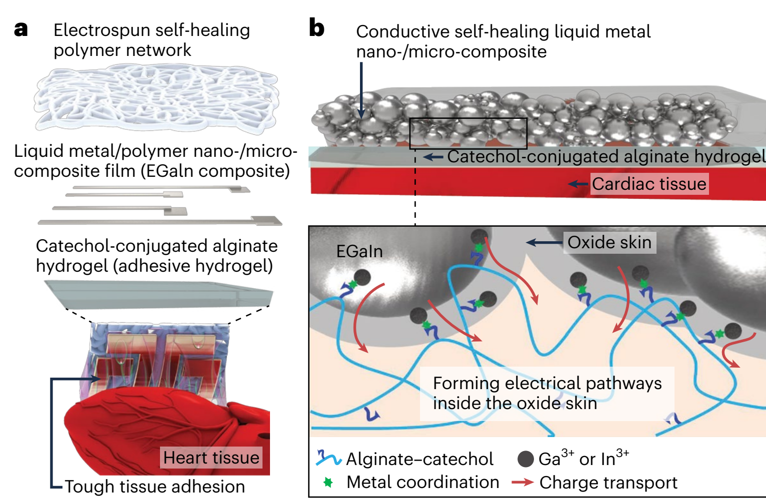

Fig. 1 | Sutureless soft bioelectronics for electrocardiogram sensing. a, Schematic illustration of the sutureless soft bioelectronic patch on heart tissue. An adhesive catechol-conjugated alginate hydrogel enables rapid adhesion to the tissue surface, the eutectic gallium indium (EGaIn) nano-/micro-composite creates fatigue-resistant electrical interconnects, and the fibrous polymer network makes the patch durable and conformable. **b**, Schematic of the bidirectional interface of the adhesive layer between the tissue and the eutectic gallium indium nano-/micro-composite (top). Electrical pathways are formed by the coordination between the alginate–catechol in the adhesive layer and the oxide skin around the eutectic gallium indium particles in the composite (bottom). Figure adapted with permission from ref. 6, Springer Nature Ltd.

or non-contact issues when attached to a beating rat heart. Moreover, the patch could precisely map, via electrocardiogram signals, the abnormal activations in a rat myocardial ischaemia–reperfusion model after one week. To illustrate the capabilities of the multilayered adhesive soft bioelectronic patch, the researchers conducted implantation experiments on freely moving rats. By eliminating the need for suturing, the patch could monitor electrocardiogram signals non-invasively and with minimal disruption to the cardiac tissue.

The sutureless bioelectronics created by Shin, Son and colleagues advances the development of devices for long-term implantable cardiac signal monitoring and electrical stimulation, and could also be used for other applications such as brain–computer interfaces. However, methods to fabricate higher-density electrode arrays for soft bioelectronics must be developed. Increasing the number of electrodes within the patch would allow for more precise and comprehensive signal monitoring and stimulation[8]. Furthermore, expanding the sutureless bioelectronics to bio-signals beyond the current focus on electrocardiogram signals — to brain and spinal-cord signals, for example[9] — is important. This potential for versatility could provide a path to diverse and innovative developments in the field of sutureless bioelectronics.

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Competing interests

The authors declare no competing interests.