Supporting Information

Highly Air/Water-Permeable Hierarchical Mesh Architectures for Stretchable Underwater Electronic Skin Patches

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Supporting Method Section

Fabrication of the hexagonal mesh pattern (HMP) master

To fabricate the HMP master, a hexagonal mesh-patterned (hexagonal shape; thickness: 250 μm, space length: 500 μm, depth: 150 μm) photoresist on a Si wafer was prepared via photolithography. The Si wafer was coated with a self-assembled monolayer (SAM) solution, FOTCS (Samchun Chemical Co., Korea) on a hotplate (100 ℃). PDMS with a curing agent (1:10 mass ratio of PDMS) was poured onto the Si wafer, followed by baking in an oven (80 ℃) for 2 h. For fabricating the OIS master via photolithography and etching, a Si mold was patterned with micro-holes (radii: 50 mm; aspect ratio: 1). After the SAM process, soft-poly(urethane acrylate) (s-PUA) was casted onto the Si wafer, which was then covered with a polyethylene terephthalate film (70 μm) for the supporting backbone. To construct the OIS master, partial filling technique was used with air bubbles trapped in micro-hole chambers, as previously reported [24]. The OIS PDMS mold was easily obtained via simple replication molding with curing in the s-PUA master.

Measuring electrical and mechanical response and normal adhesion strength

The electrical resistance of the CPC electronics (1 × 1 cm^2, thickness: 100 mm) was measured at a constant current of 10 mA using a source meter (SMU, National Instruments PXIe-4139) while the contact resistances were minimized by covering the joint with Ag paste. Additionally, the mechanical properties (SS curve) were measured and a tensile strain was applied using custom-built equipment (Neo Plus, South Korea). The surface morphologies were examined via field-emission SEM (JSM-7200F).

The normal adhesive strength was measured using custom-built equipment (Neo Plus, South Korea). The CPC with the OIS patch was attached to a segment of a pigskin replica (Ecoflex 0030, Smooth-on Inc., USA) with a preload (1 N/cm^2) in dry, wet, and underwater conditions.

All measurements were performed at least 10 times at room temperature (23 ~28 ℃), and the average values are presented along with the standard deviations.

Measuring bio-signals, ECG, and human motion

Two identical HMP CPC electrode patches and a ground electrode were attached to both wrists and the left leg of a volunteer. All electrodes were connected to an ECG module (ADS1 × 9xECGFE, Texas Instruments). ECG signals were measured in the bending condition and in an underwater environment. Human motion was measured with sensors attached to the finger of a volunteer. The finger was bent from 0° to 75° in 10-s intervals. Following school board policies, an approval from the Institutional Review Board (IRB) was initially received for both subject and parental assent (IRB Approval No. SKKU 2018-05-012).

Adhesive Mechanism of the OISs in Wet Conditions

Overall normal adhesive stress($\sigma_{o,wet}$) created by the molecular interactions between the OIA array and the wet solid surface can be expressed as the sum of the suction force ($\sigma_{s,wet}$) and the capillary force (σ_c): $\sigma_{o,wet} = \sigma_{s,wet} + \sigma_c$. When the OISs contact with a solid wet surface by an applied preload, the chamber of the OISs is separated by the contact between the dome-like architecture and nearby sidewalls. By this deformation, the capillary force drains the residual liquid toward additional chamber. With removal of preload force, elastic relaxation generates a low pressure in the bottom chamber near the substrate, relative to the ambient pressure (ΔP_0) (nearly creating a vacuum state, ($\Delta P_{max} = \Delta P_0 - \Delta P_{BC}$). The suction stress ($\sigma_{s,wet}$) induced by the capillary-assisted pressure drop in the lower chambers can be described as follows: $\sigma_{s,wet} = -\Delta P_{max} \pi r^2 \kappa n$. κ is the yield of OISs (around 0.71 for a radius of 30 μm); and *n* is the number of OISs per unit area (7×10^3 cm^{-2} for a radius of 30 μm); *r* can be determined from the following geometric description of the OIAs: $r \approx \sqrt{(2R + l)D_a}$ [1].

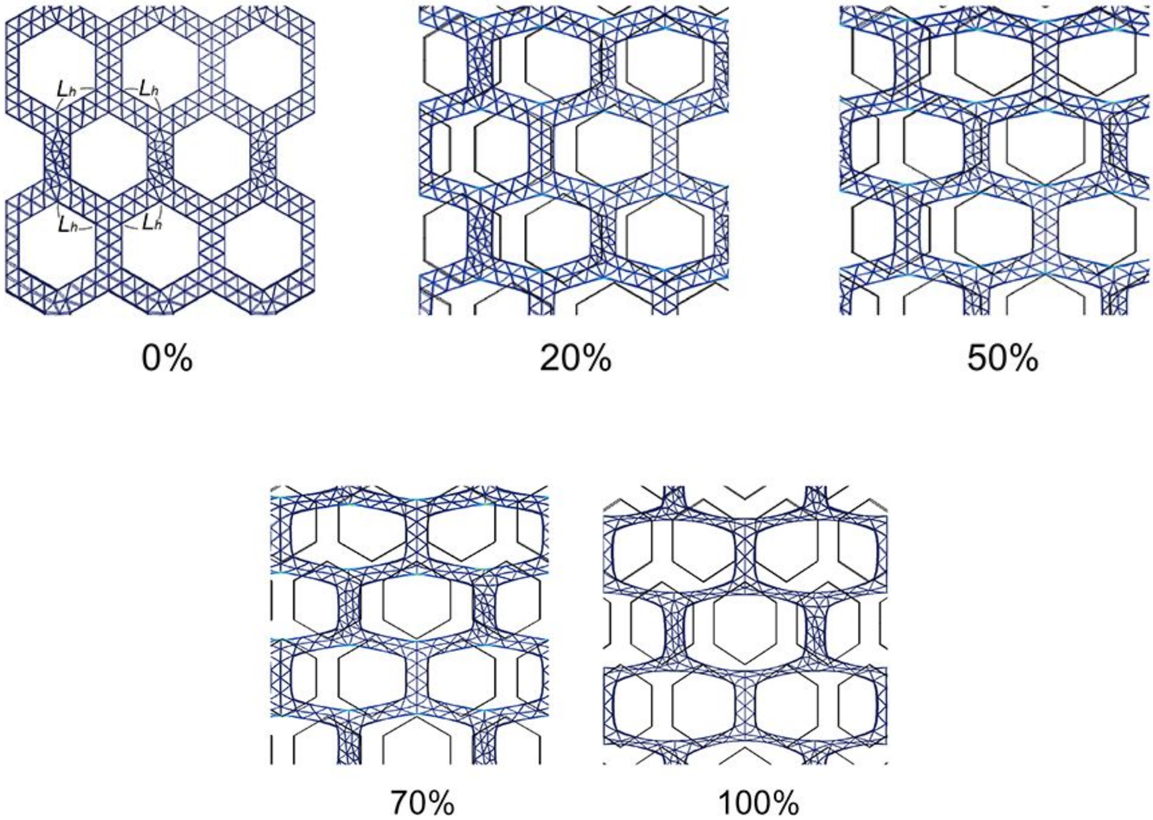

Figure S1. FEM simulation images showing the deformation of the hexagonal mesh structure under an applied strain (~100%).

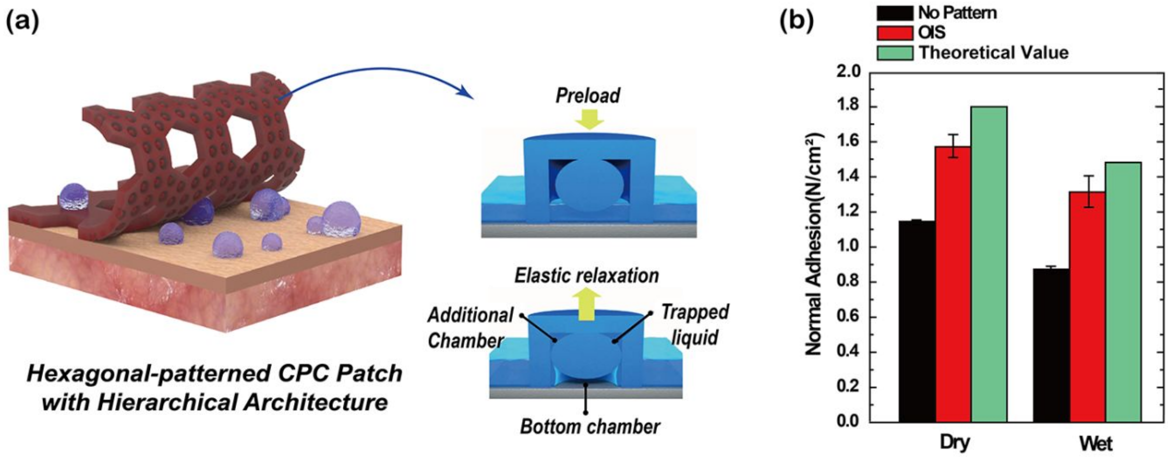

Figure S2. Mechanism of Octopus inspired structure's adhesive capability. (a) Process of OISs' adhesion. (b) Normal adhesion strength for the flat film, OIS film, and theoretical value in dry, wet conditions on a skin replica with a preload of 1.0 N cm^{-2}

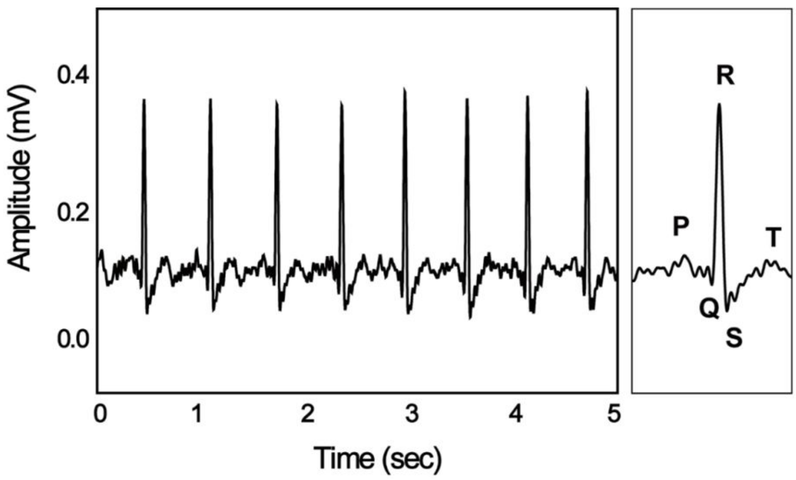

Figure S3. ECG signals measured by commercial electrodes.

REFERENCES

1. Baik, S., Park, Y., Lee, T. J., Bhang, S. H., & Pang, C. A wet-tolerant adhesive patch inspired by protuberances in suction cups of octopi. *Nature*, **2017**, 546, 396.