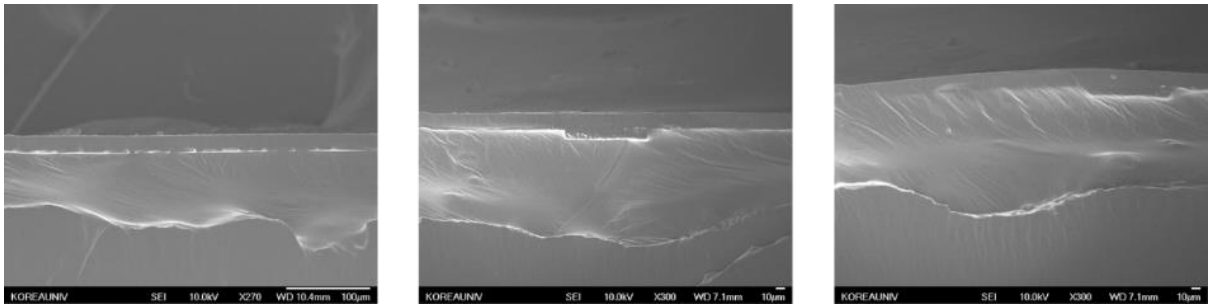
Supplementary Information for

Self-adhesive epidermal carbon nanotube electronics for tether-free long-term continuous recording of biosignals

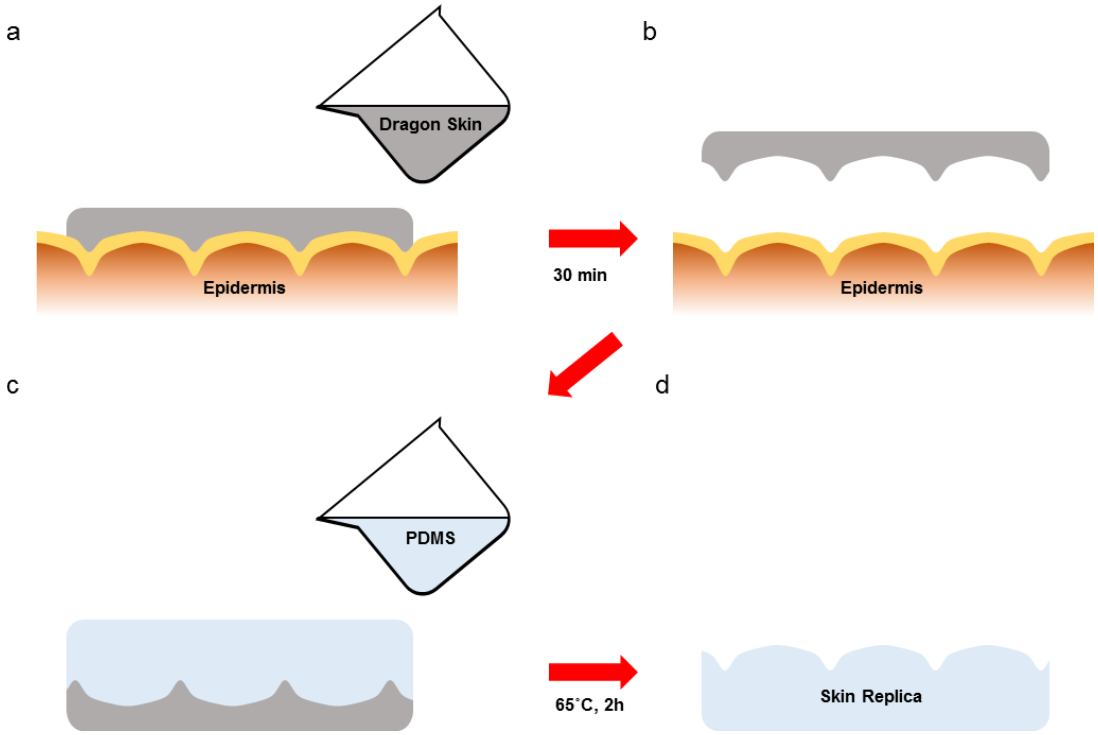
Seung Min Lee, Hang Jin Byeon, Joong Hoon Lee, Dong Hyun Baek, Kwang Ho Lee, Joung Sook Hong, Sang-Hoon Lee

Supplementary Figures

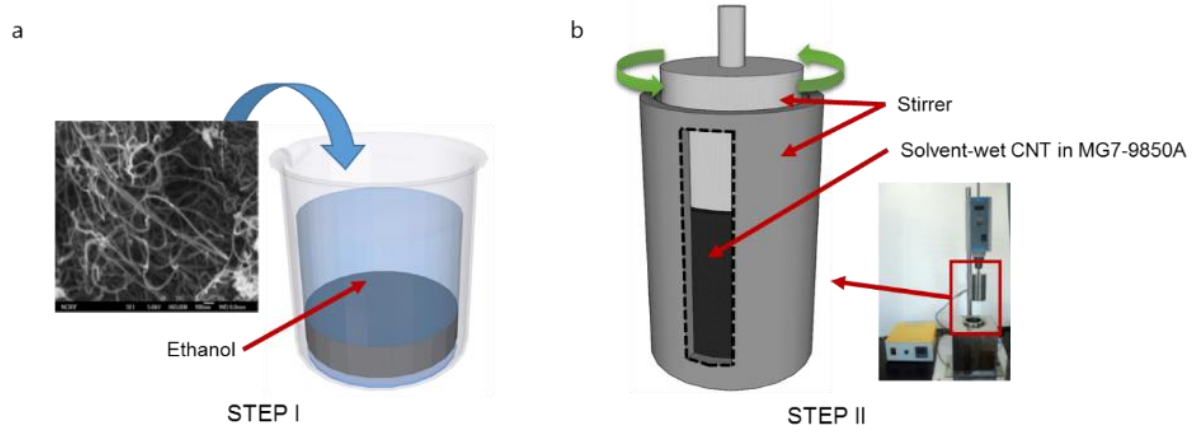
Supplementary Figure S1. Penetration to the skin replica. Penetrated CNT/aPDMS into various wrinkled surface of the skin replica made of PDMS.



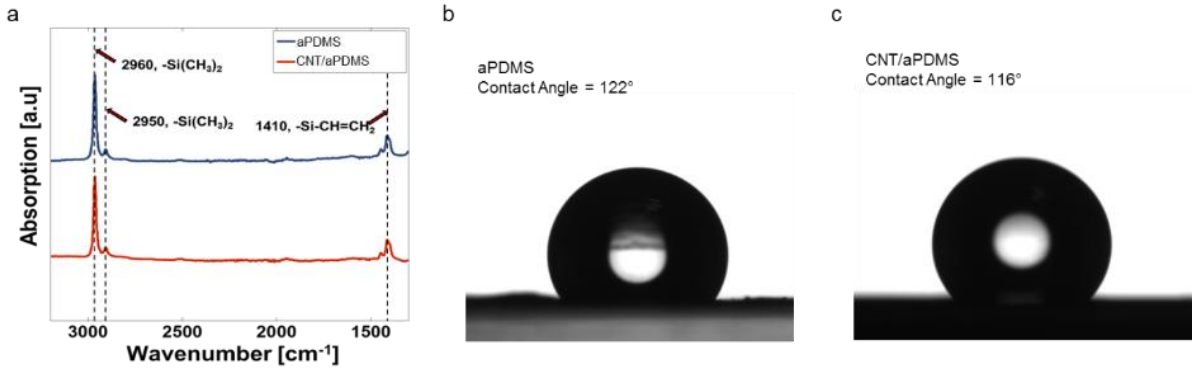
Supplementary Figure S2. Fabrication of the skin replica. (a) Dragon Skin was cast onto the chest then cured for 30 min to form a solid mold. (b) The cured Dragon Skin was peeled off the chest. (c) The mold was turned over and PDMS was poured onto it. (d) After curing for 2 hours in a 65˚C oven, the PDMS skin replica was peeled off.



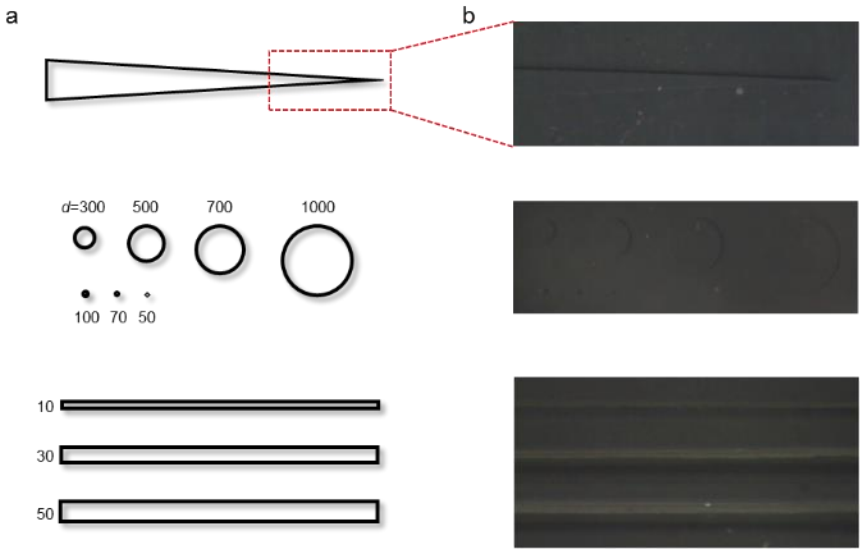
Supplementary Figure S3. Protocol for the mixing of CNTs and adhesive PDMS. (a) CNTs were placed in ethanol to prepare solvent-wet CNTs. (b) The solvent-wet CNTs were mixed with MG 7-9850A (5 wt%) then dispersed under shear flow stress induced with a home-made stirrer.



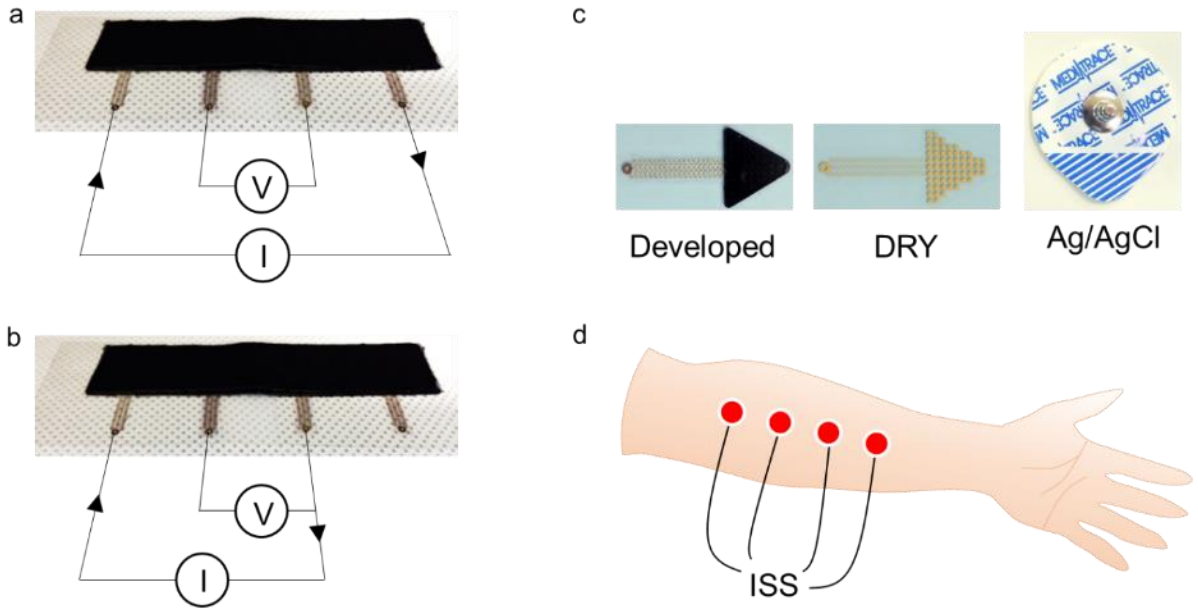
Supplementary Figure S4. Chemical properties of CNT/aPDMS. (a) FTIR results for aPDMS (blue) and CNT/aPDMS (red) indicate that there are no chemical changes when CNT is mixed into aPDMS. Images of 5 μL water droplets on (b) aPDMS and (c) CNT/aPDMS. The contact angles are 112˚ and 116˚ respectively.



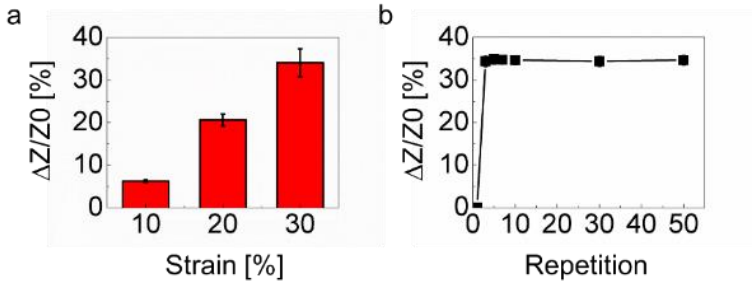
Supplementary Figure S5. Penetration to the diverse shaped grooves of PDMS. (a) Various groove-patterns for penetration test. (unit: μm) (b) Microscope images of each patterns observed from bottom of the PDMS indicated all aPDMS was successfully penetrated and contacted.



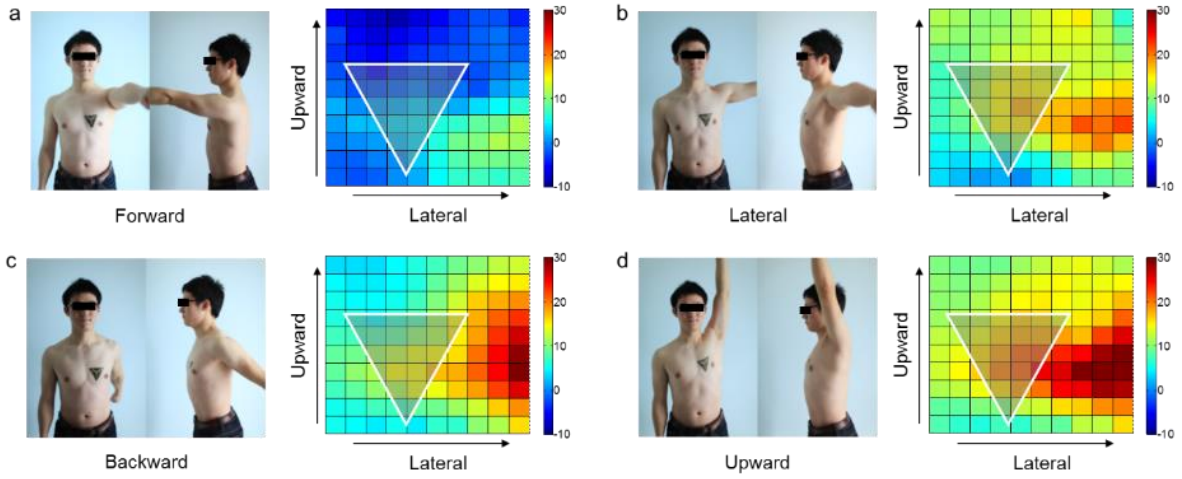
Supplementary Figure S6. Impedance measurements protocol. Experimental set-up for measuring the intrinsic impedance of CNT/aPDMS with (a) four and (b) three probes. The four-probe impedance is ZC, and ZCM was calculated by subtracting ZC from the impedance measured with three probes. ZCE was measured with the same protocol for the CNT/aPDMS, dry, and conventional Ag/AgCl electrodes in (c).



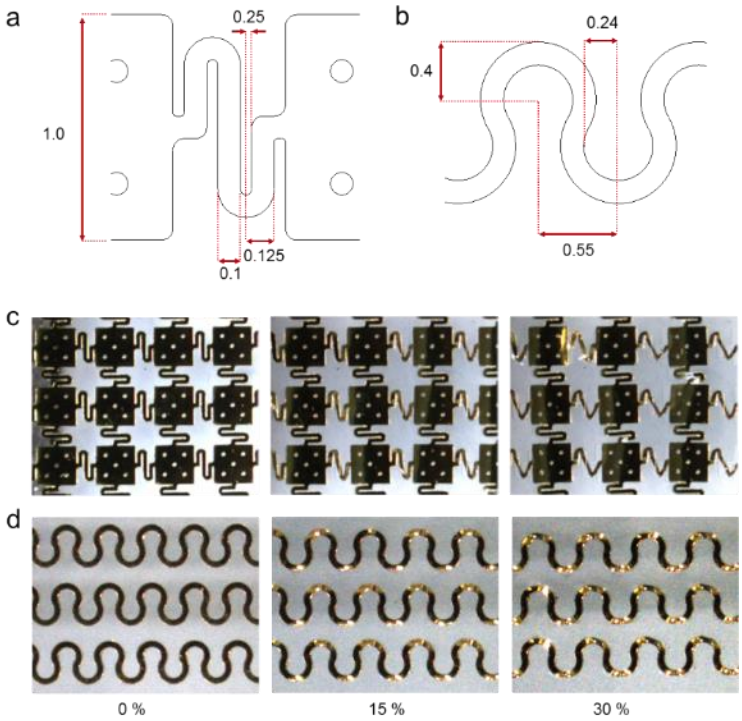
Supplementary Figure S7. Strain test of CNT/aPDMS. (a) Change of impedance of CNT/aPDMS according to applied strain and (b) repeating strain test by applying 30% tensile strain.



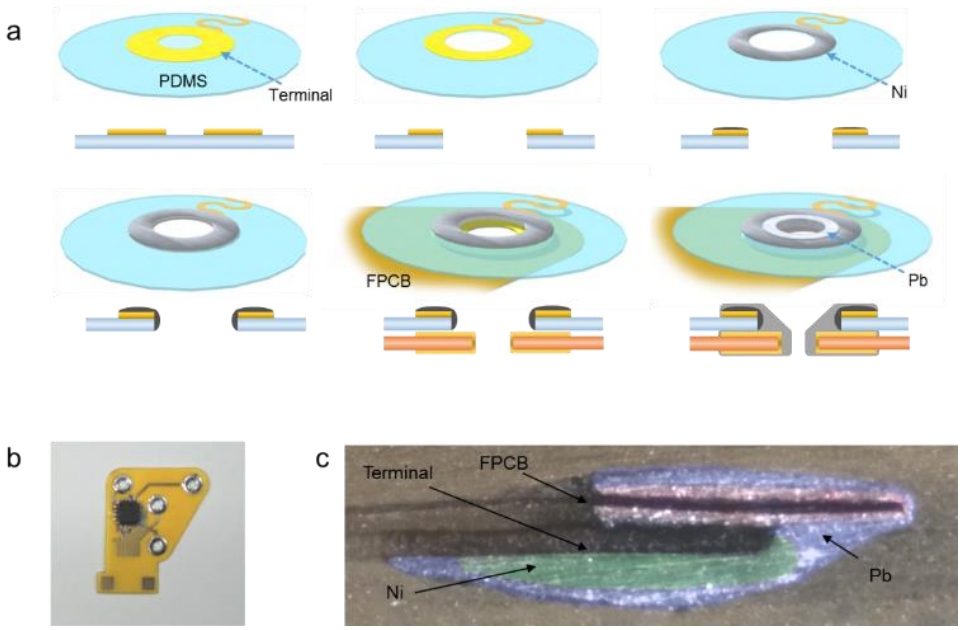
Supplementary Figure S8. Stretching ratio of the skin. The stretching ratio of the skin was determined for the following motions of the left arm: (a) forward, (b) lateral, (c) backward, and (d) upward. The location where the ECG electrode would be attached is enclosed by the white triangle.



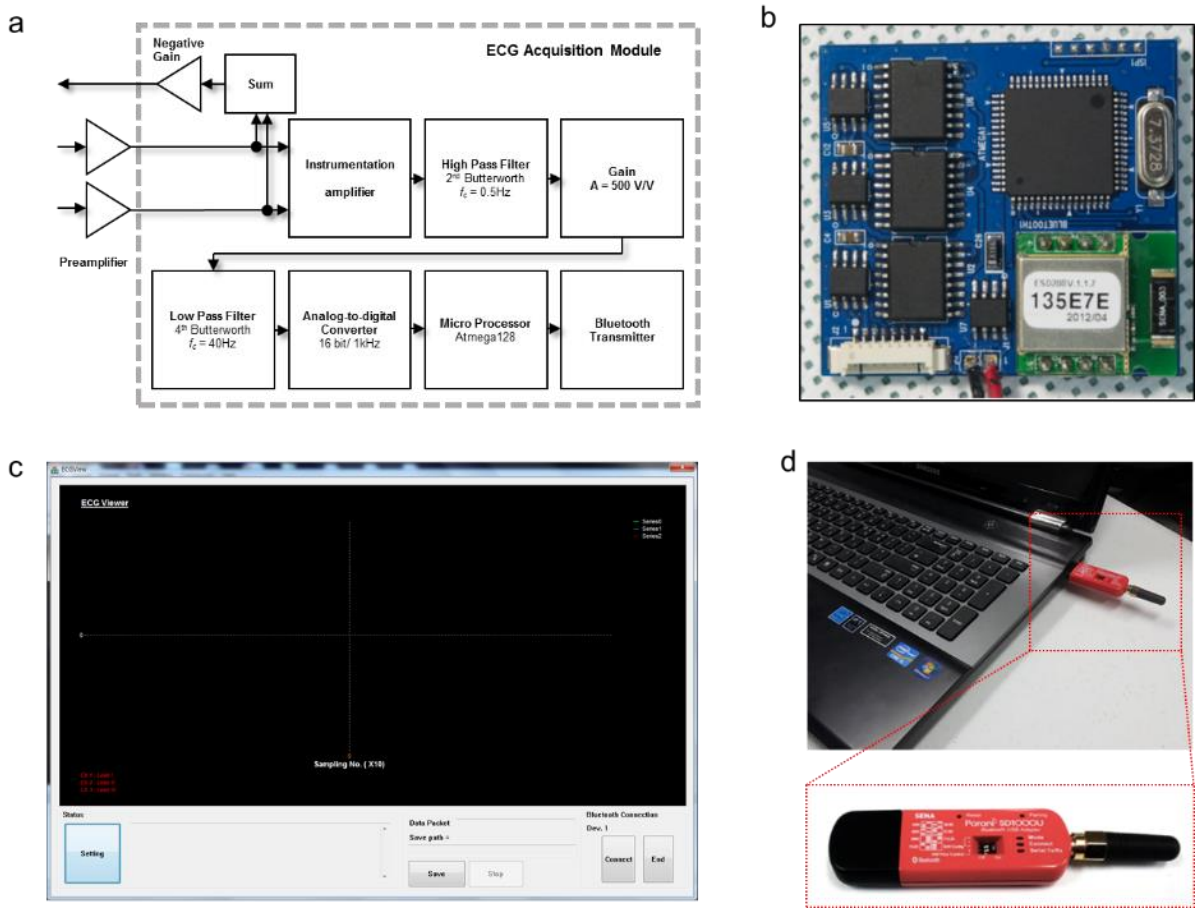
Supplementary Figure S9. Electrode serpentines. Assembly drawings of the serpentines: (a) ELE and (b) serpentine line (unit: mm). Optical images of (c) ELE and (d) serpentine line under strain stresses of 0, 15, and 30% in the x-direction.



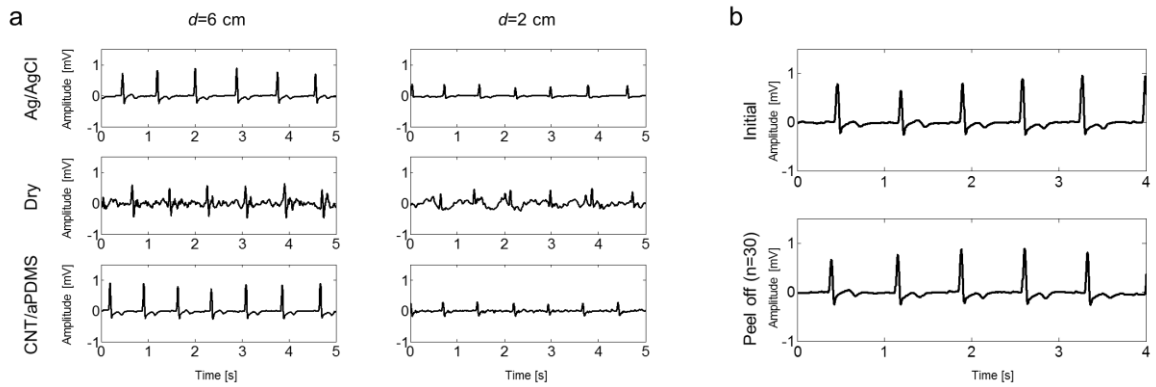
Supplementary Figure S10. Solderable terminal. (a) The Ni electroplating procedure. Electroplating was applied to the terminal with a hole, and the hole was covered with Ni to enable soldering. (b) FPCB with a preamplifier and a commercialized connecter. (c) Cross-sectional view of the terminal and the FPCB.



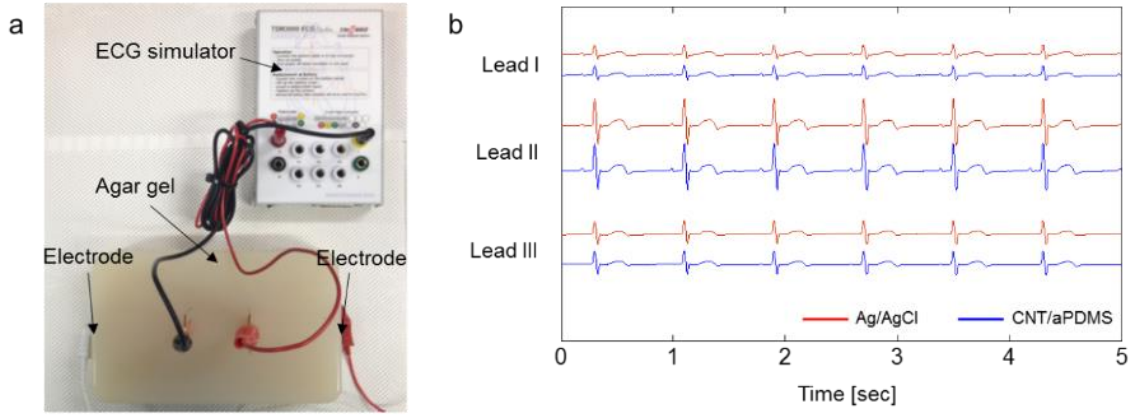
Supplementary Figure S11. Data Acquisition System (a) Block diagram of the designed signal acquisition module and (b) the fabricated PCB including amplifiers, filters, a microprocessor, and a Bluetooth module. (c) Real time data receiving program. (d) USB-type Bluetooth dongle.



Supplementary Figure S12. Reliability. (a) ECG waveforms from Ag/AgCl, Dry, and CNT/aPDMS electrode according to the distance between electrodes. (b) ECG waveforms before and after 30 cycles of peel off process without any cleaning procedure.

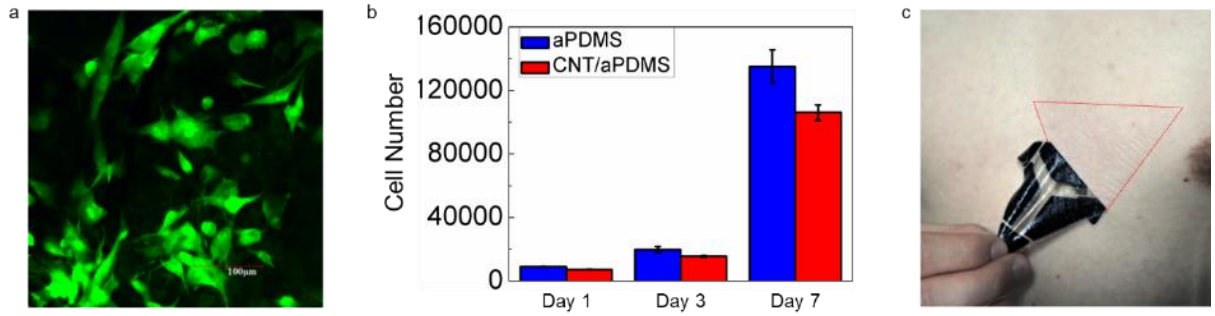


Supplementary Figure S13. Accuracy test. (a) Experimental set-up for ECG recordings from the ECG simulator attached to agarose gel. (b) ECG waveforms recorded with Ag/AgCl and CNT/aPDMS electrodes.

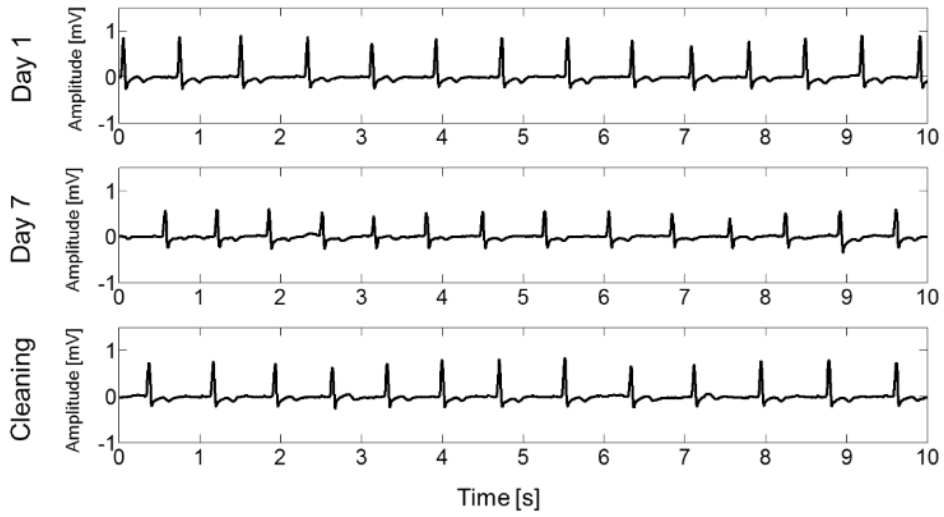


Supplementary Figure S14. Waterproof test. (a) Part of the CNT/aPDMS electrode was attached to the arm of a subject and blue-colored water was poured over it and rubbed in with a finger. (b) The water did not penetrate the area in contact with the CNT/aPDMS electrode. (c) Schematic diagrams of a normal dry electrode and a soft and self-adhesive electrode attached to skin and exposed to water.

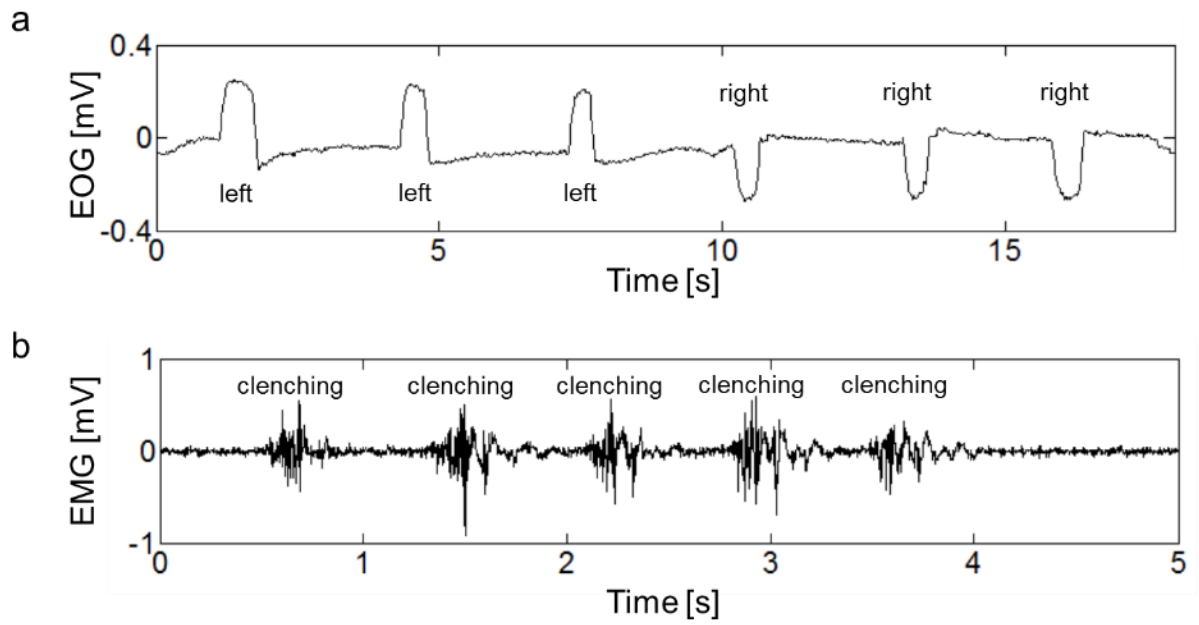
Supplementary Figure S15. Biocompatibility test. (a) Cytotoxicity test using human fibroblast cells. Most cells are alive (green) although there are a few dead cells (red). (b) The result of CCK test for day 1, 3, and 7. (c) Skin compatibility was confirmed by placing the CNT/aPDMS electrode on the chest of a subject continuously for a week, after which time the skin under the electrode was found to be normal.



Supplementary Figure S16. Long-term measurement. ECG waveforms of the first day, a week later, and after the cleaning procedure.



Supplementary Figure S17. Other biosignals. (a) Horizontal EOG recording for three left and right seeing. (b) EMG recording from an arm during fist clenching and releasing.



Legends of Videos

Video S1: Waterproof test. By attaching part of ECG patch to the forearm blue-colored water was stained. After rubbing with a finger several times, water was removed by a tissue and the electrode was peeled off. The water did not penetrated where the electrode was attached.

Video S2: ECG measurement in a water-filled bath. Wearing the ECG patch, a subject entered water-filled bath and ECG signal was recorded.