

Long-Term In Vivo Operation of Implanted Cardiac Nanogenerators in Swine

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S1. Figures and Captions

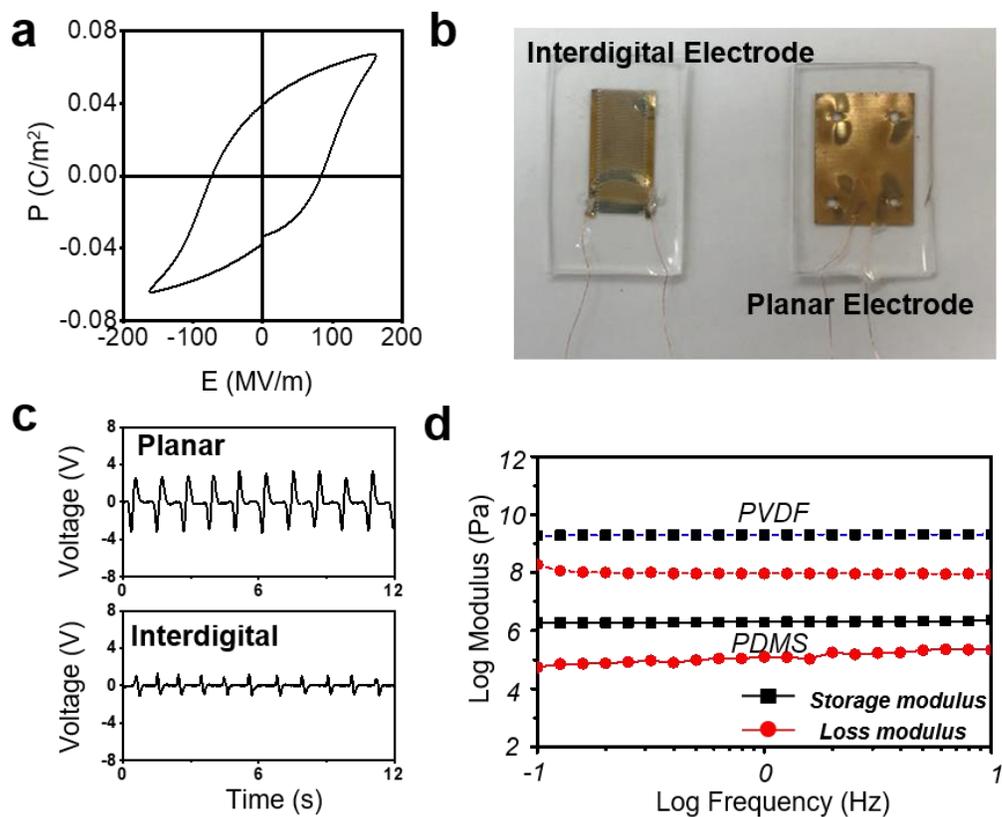


Fig S1. (a) Polarization-electric field (PE) loop of ferroelectric PVDF thin film. (b) Digital image of i-NGs with different electrode configurations. (c) Voltage outputs of i-NGs with different electrode configurations. (d) Dynamic mechanical analysis of PVDF and PDMS thin film under different frequencies.

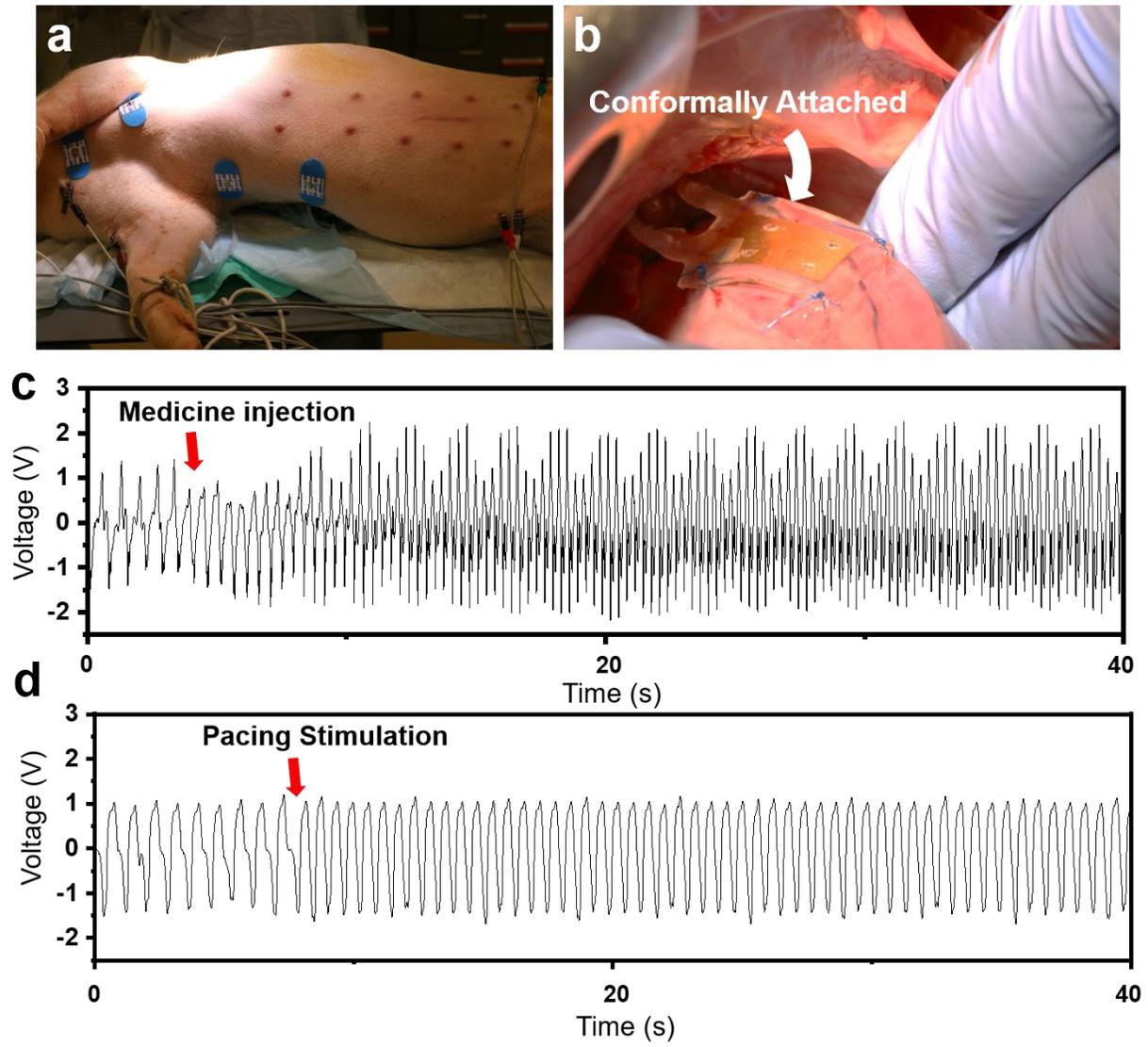


Fig S2. (a) Digital image of swine connected with ECG pads. (b) Digital image of i-NGs conformally attached on the surface of heart. (c) Voltage outputs of implanted i-NGs before and after the injection of dobutamine to swine. (d) Voltage outputs of implanted i-NGs before and after the pacing of swine heart by an epicardial pacemaker.

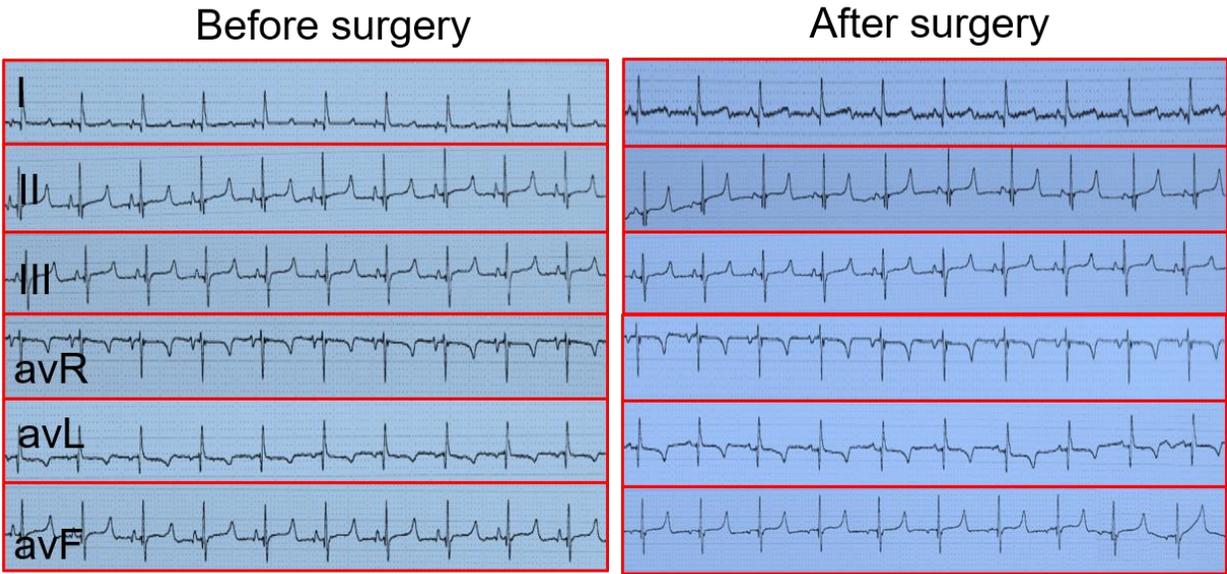


Fig S3. Six-channel ECG signals of swine prior-implantation and post-implantation of i-NG.

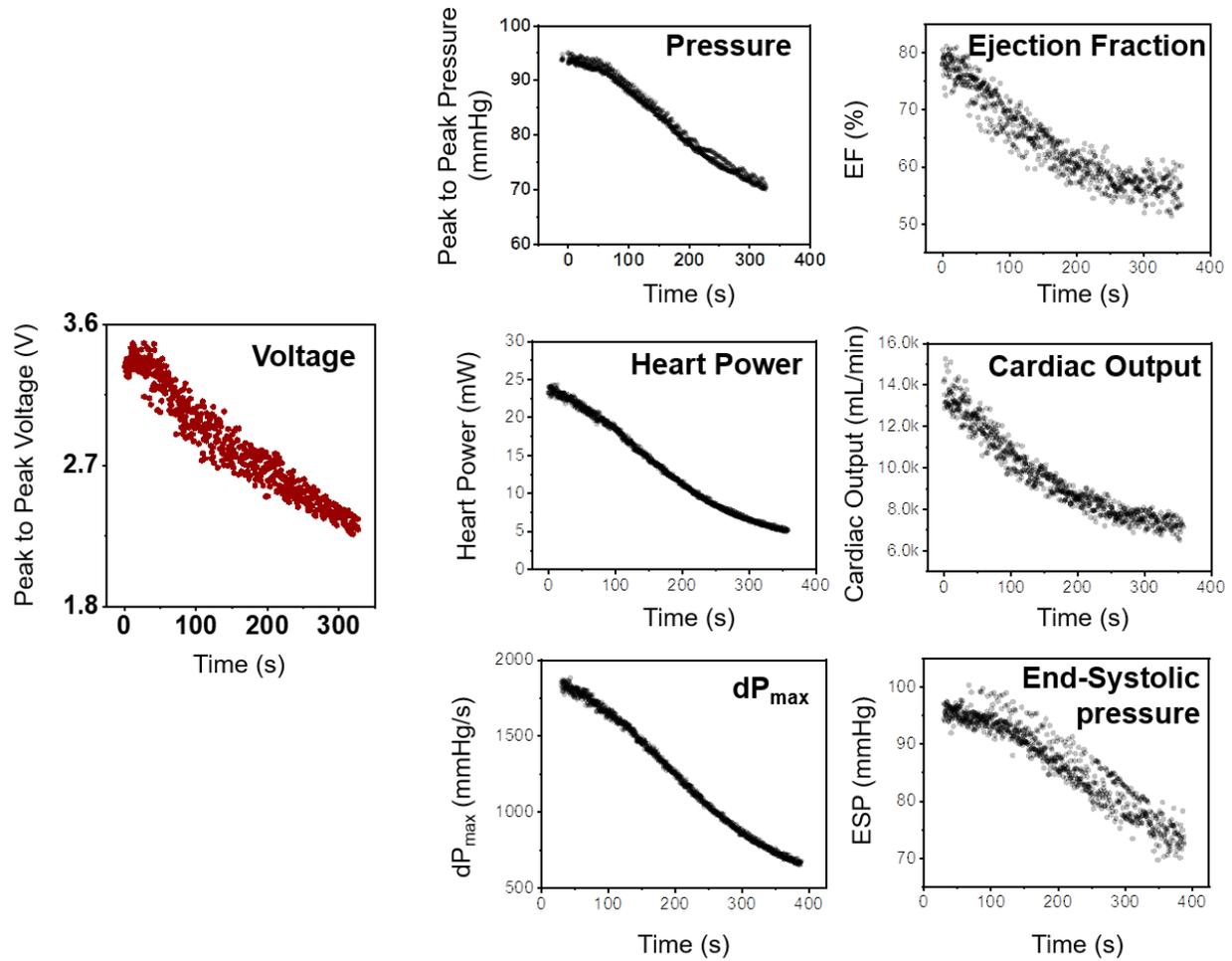


Fig S4. The variation of i-NGs voltage outputs in analogy to the changes in several important cardiac parameters such as pressure, ejection fraction (EF), heart power, cardiac output (CO), dP_{max} , end-systolic pressure. A strong correlation can be found between V_{pp} and these parameters.

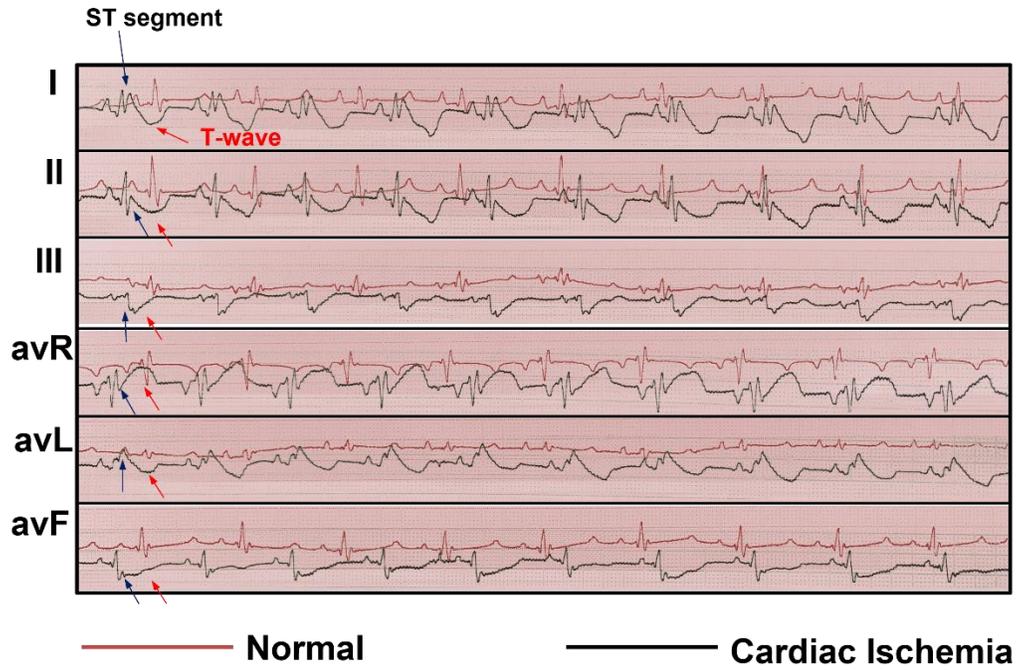


Fig S5. ECG signals of swine in normal condition and cardiac ischemia.

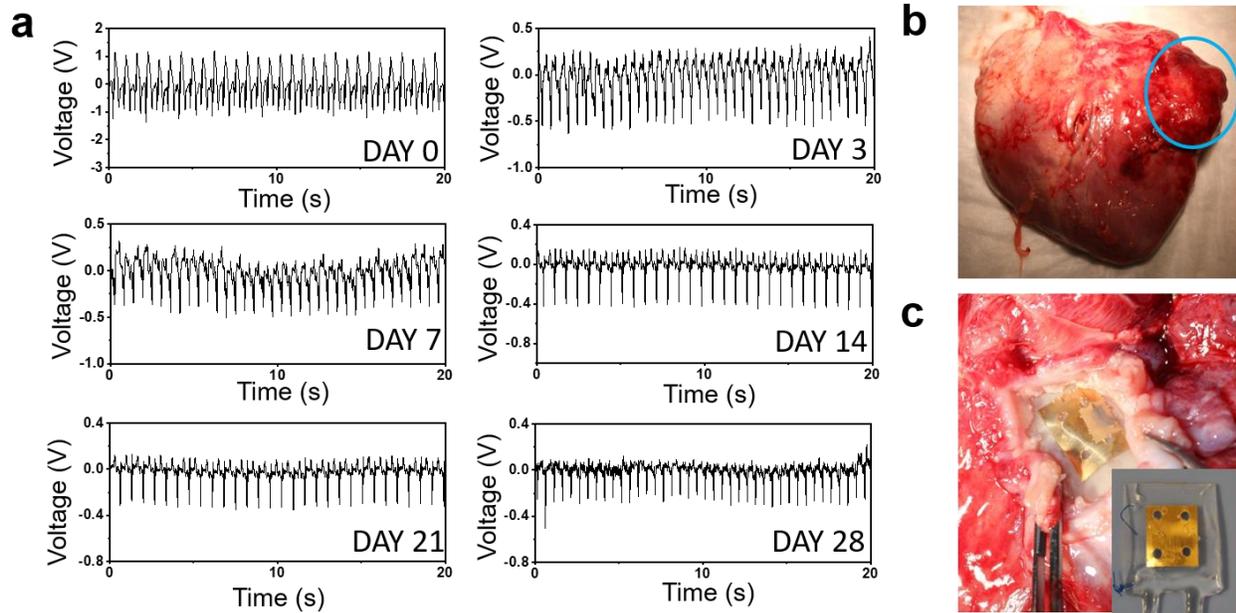


Fig S6. (a) Voltage outputs of implanted i-NG at different time points. (b) Harvested heart from swine embedded with i-NG. The blue circle indicated the location where i-NG was implanted. (c) The fouling of i-NG on heart by forming fibrous capsule around it. Inset is the i-NG by removing the capsule, revealing a good integrity without damages.

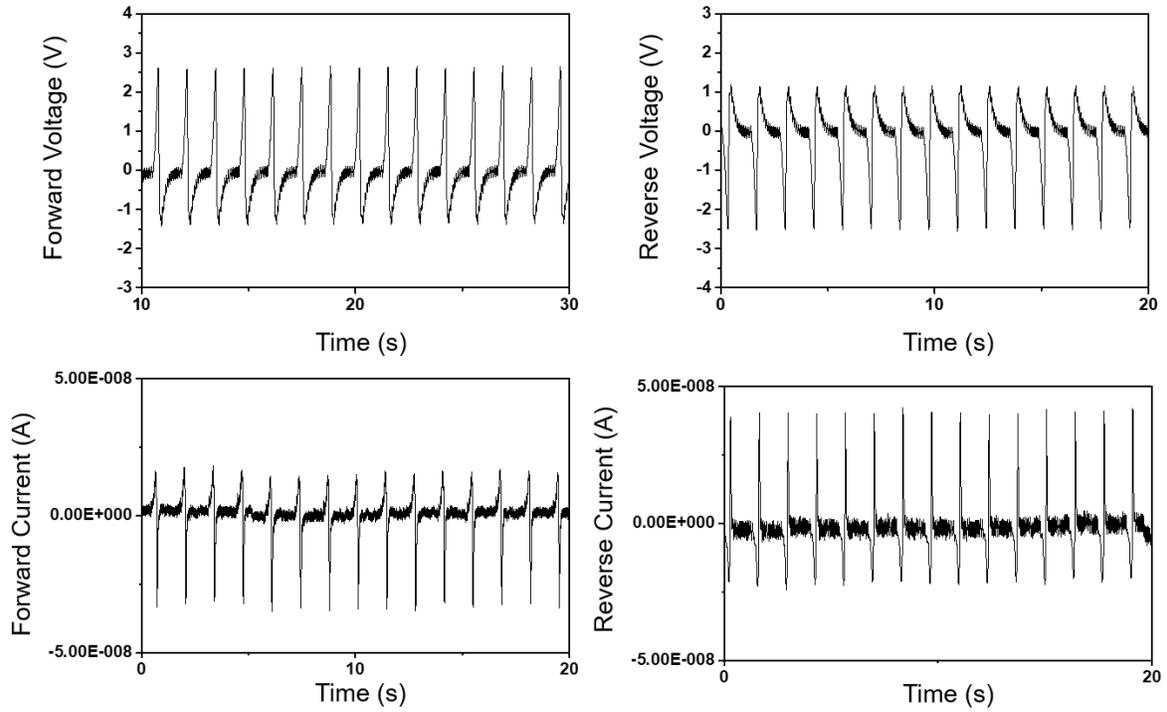


Fig S7. Voltage and current outputs of extracted i-NG after 2-month implantation under in vitro tests. The extracted i-NG exhibited the same outputs as those obtained prior-implantation.

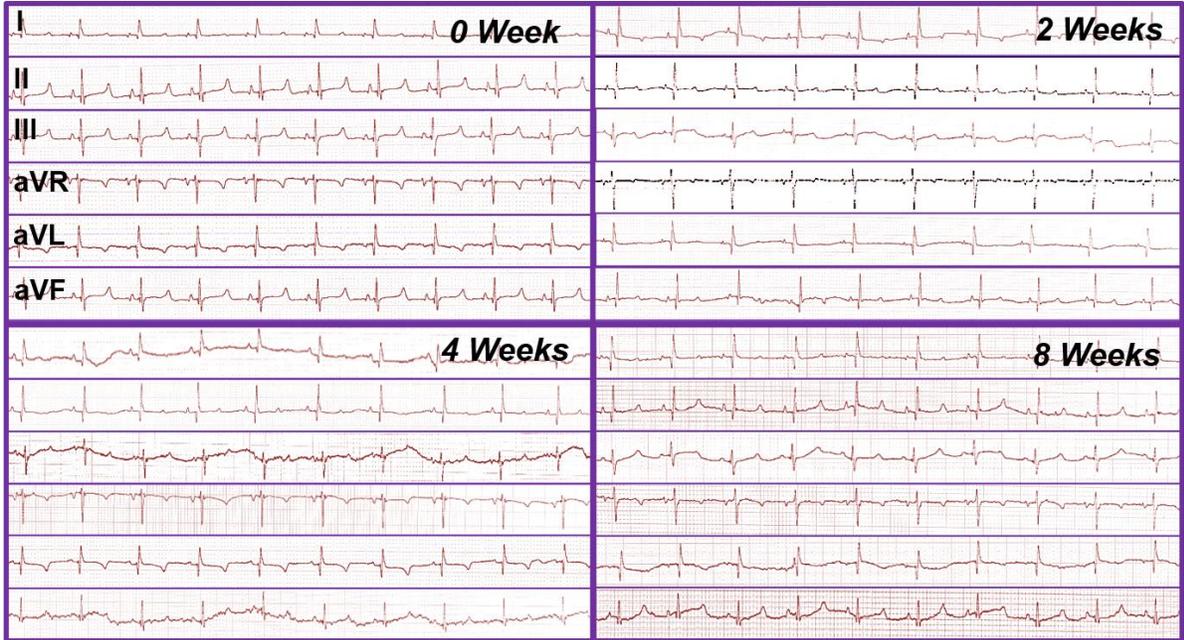


Fig S8. Six-channel ECG signals of swine embedded with i-NGs during the implantation.

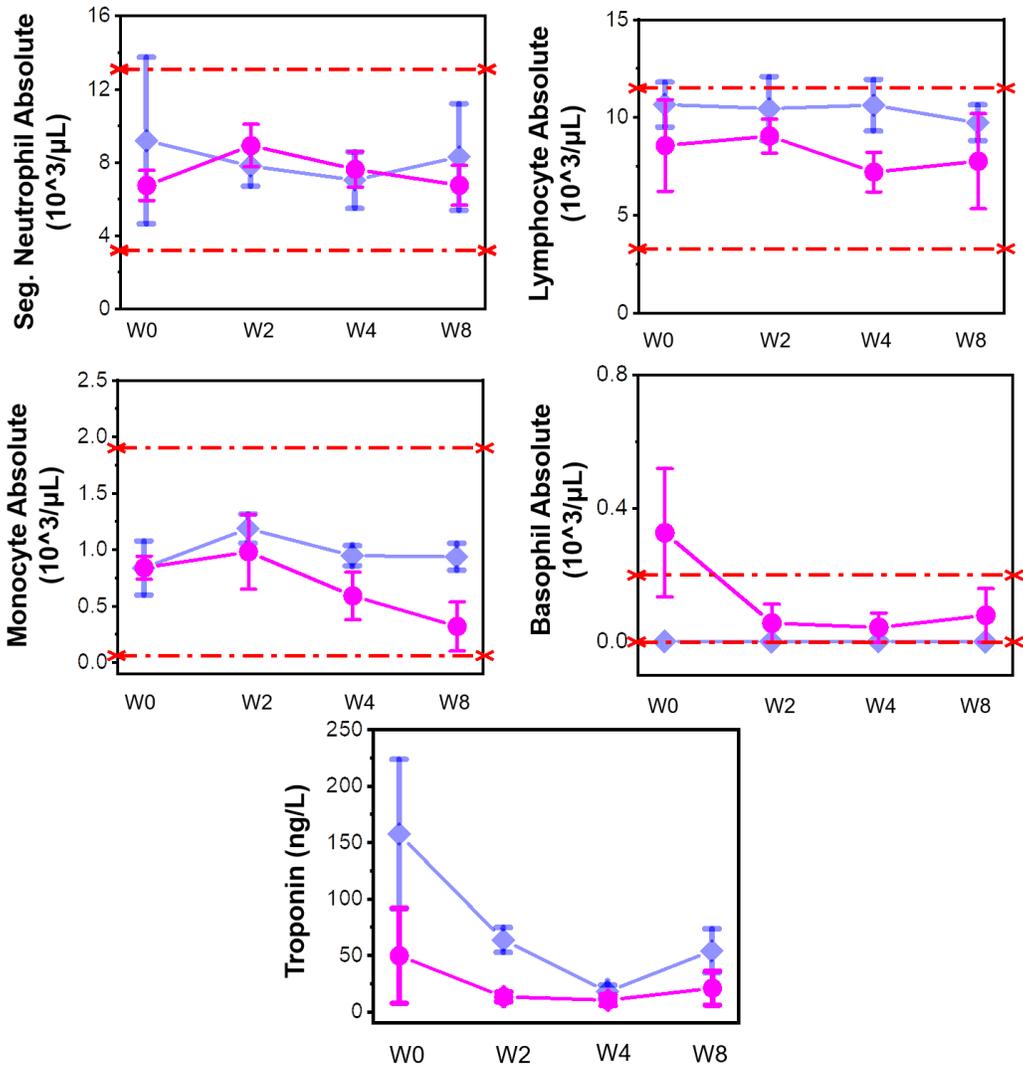


Fig S9. Blood and serum analysis of swine embedded with i-NGs during the implantation. Neutrophils, monocytes, lymphocytes, and basophil are the common while blood cells as indicators of infection. Troponin I, a cardiac muscle protein regulating the muscular contraction, is related to cardiac damage and injury.

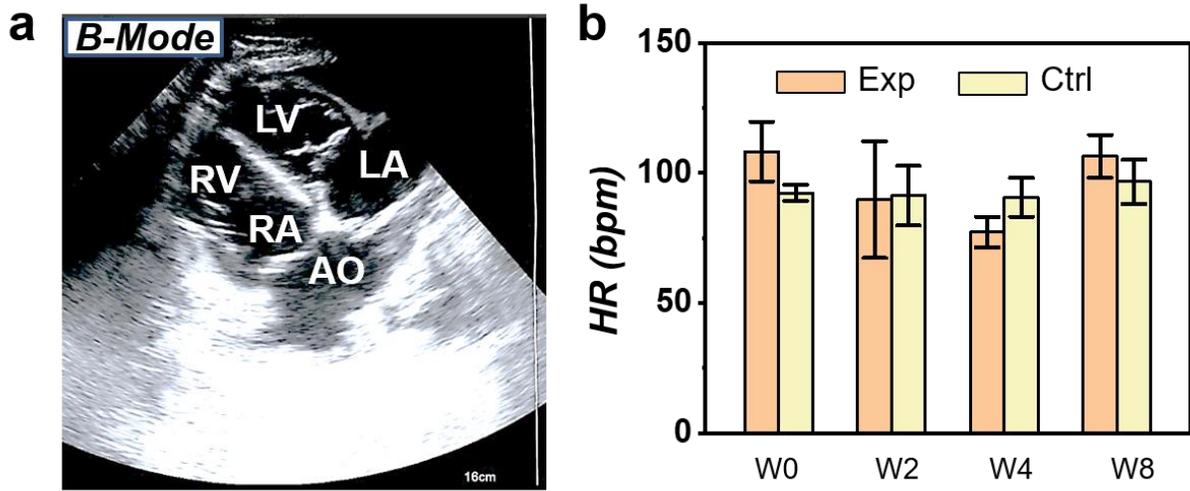


Fig S10. (a) The visualization of the whole heart structure under the B-mode of ultrasound imaging. (b) Heart rate of two groups of swine measured by transthoracic ultrasound. HR stands for heart rate.

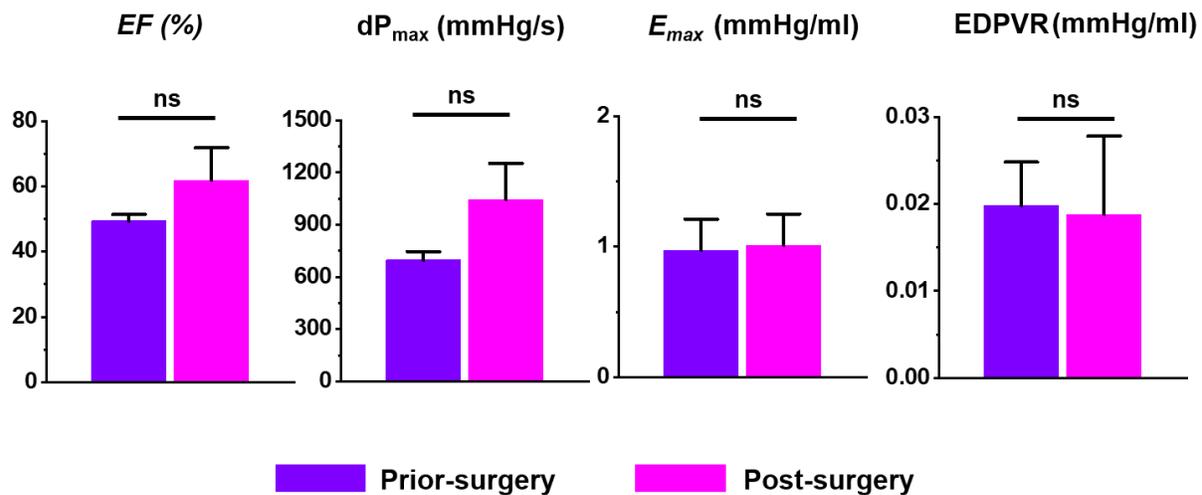


Fig S11. Comparisons of typical indicators related to heart functions derived from the PV loops prior-implantation and post-implantation in the control group. All parameters exhibited similar results to that of the experiment group.

SI2. Long-term output power and efficiency

Both output power and efficiency are directly related to the voltage output as measured in the manuscript. The output power (U) is directly related to the voltage output (V) and load resistance (R) according to the equation below:

$$U = \frac{V^2}{R} \quad (\text{S.1})$$

The output power of i-NG at the input impedance (load resistance) of voltage meter can be therefore estimated. As specified in the manuscript, the voltage meter we used is SR560 low-noise voltage preamplifier from the Stanford Research Systems. Its input impedance is constantly as 100 MΩ. Meanwhile, the overall energy conversion efficiency (η) can be estimated based on the input mechanical power (W) and output power (U):

$$\eta = \frac{U}{W} = \frac{V^2}{RW} \quad (\text{S.2})$$

The input mechanical power to the i-NG is the product of the total heart power (W_{tot}) and ratio (λ) of i-NG area to heart area.

$$W = \lambda W_{\text{tot}} \quad (\text{S.3})$$

Given the also constant functional area of i-NG and heart, and heart power (based on the heart characterization), the efficiency η is mostly determined by voltage output. Since the voltage outputs of i-NG dropped at the first week and levelled off at 0.5 V at later implantation, both output power and efficiency should follow the same trend as it, and this variation is also attributed to the fouling of the device.