Supplementary Materials

A temporally biosynchronized and physically transient peripheral nerve interface

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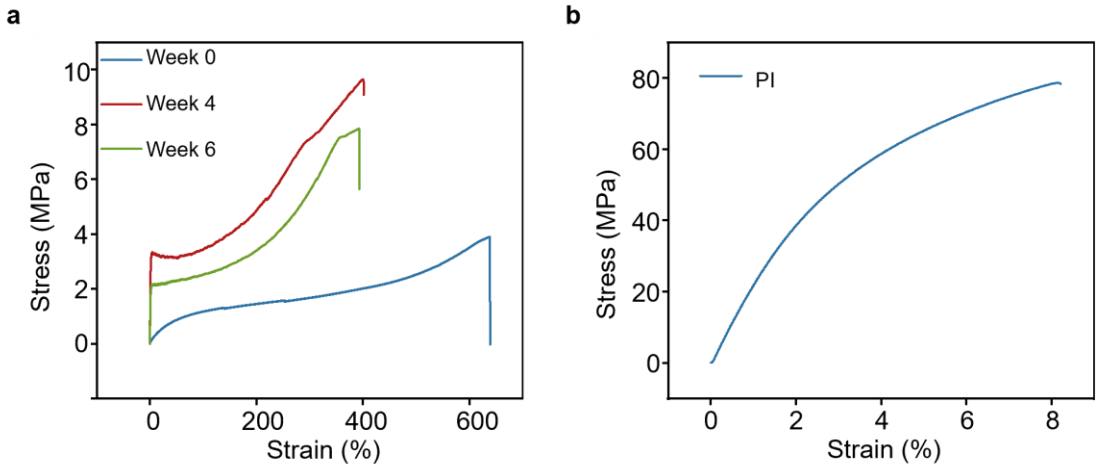
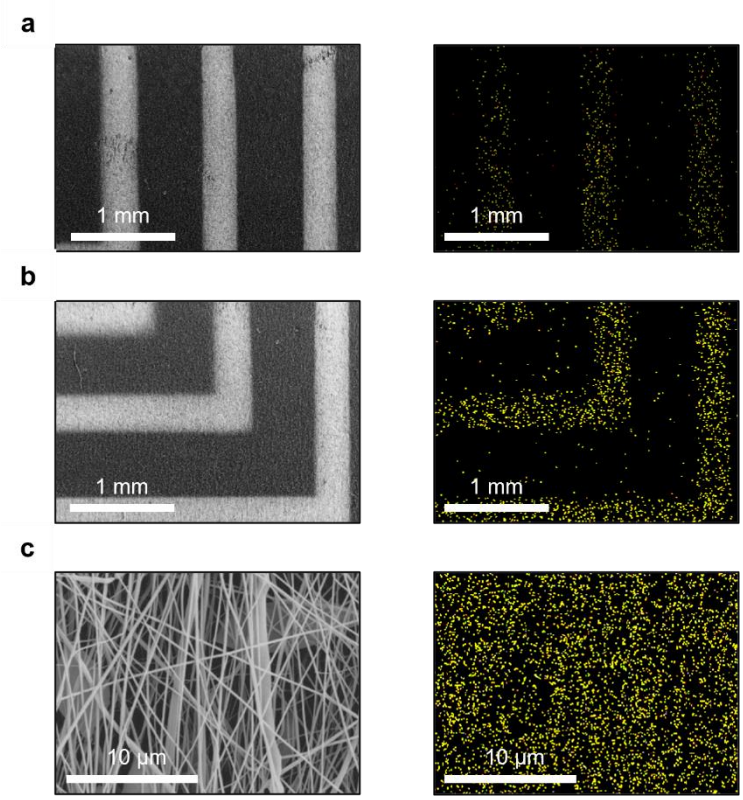
Supplementary Figure 1



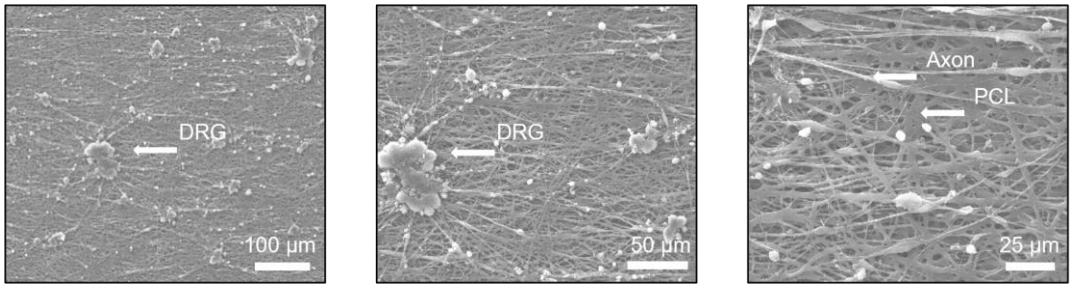
Supplementary Figure 1 | a Tensile tests of PLLA-PTMC after immersion in PBS (pH 7.4, 37 ºC) over a time frame of 6 weeks (Elastic modulus: 2.2 MPa, 365.3 MPa, 359.1 MPa in week 0, 4, 6 respectively. Breaking elongation: 638.7%, 401.4%, 393.7% in week 0, 4, 6 respectively.) **b** Tensile test of non-biodegradable polymer PI (Elastic modulus: 2398.7 MPa. Breaking elongation: 8.2%).

Supplementary Figure 2



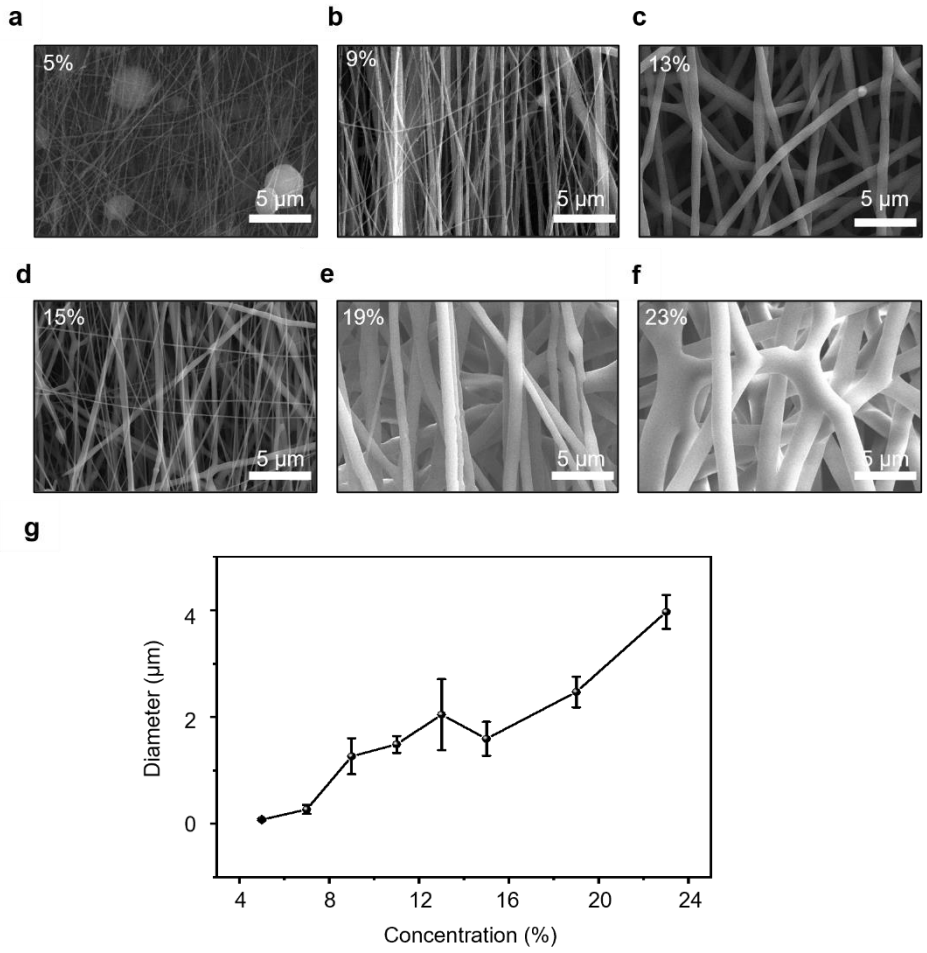
Supplementary Figure 2 | SEM (left) and EDS (right) images of device surface.

Supplementary Figure 3



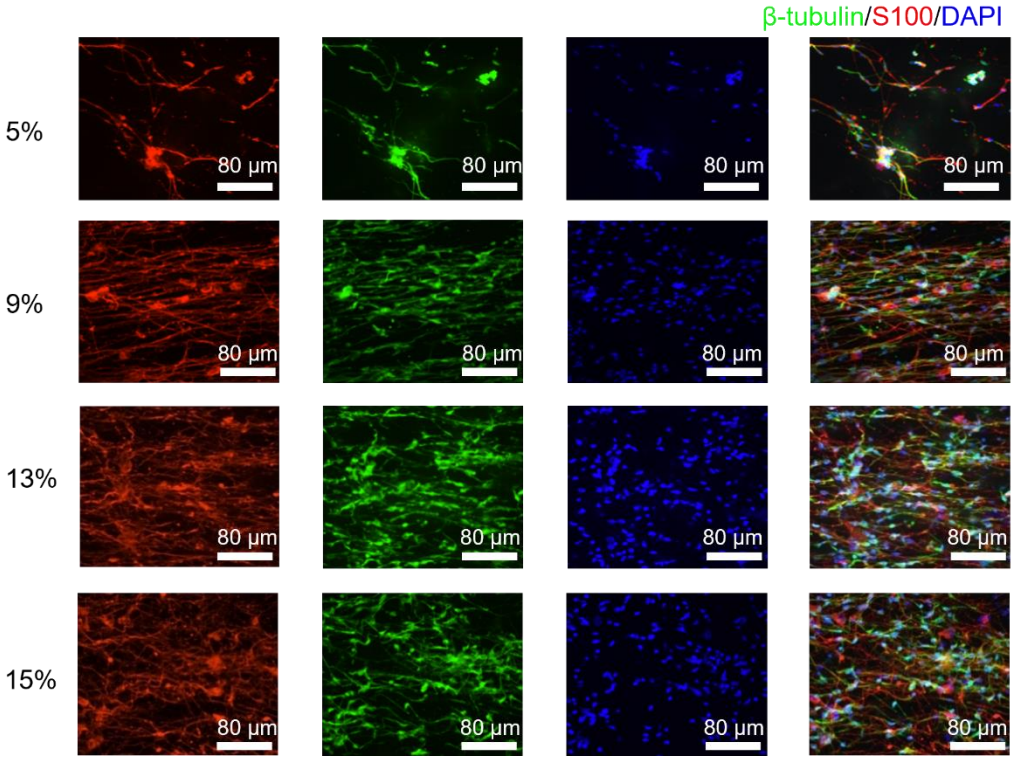
Supplementary Figure 3 | SEM micrographs show that the DRG growth morphology on 9% PCL surface after 7th day cell culture. *n* = 3 samples.

Supplementary Figure 4



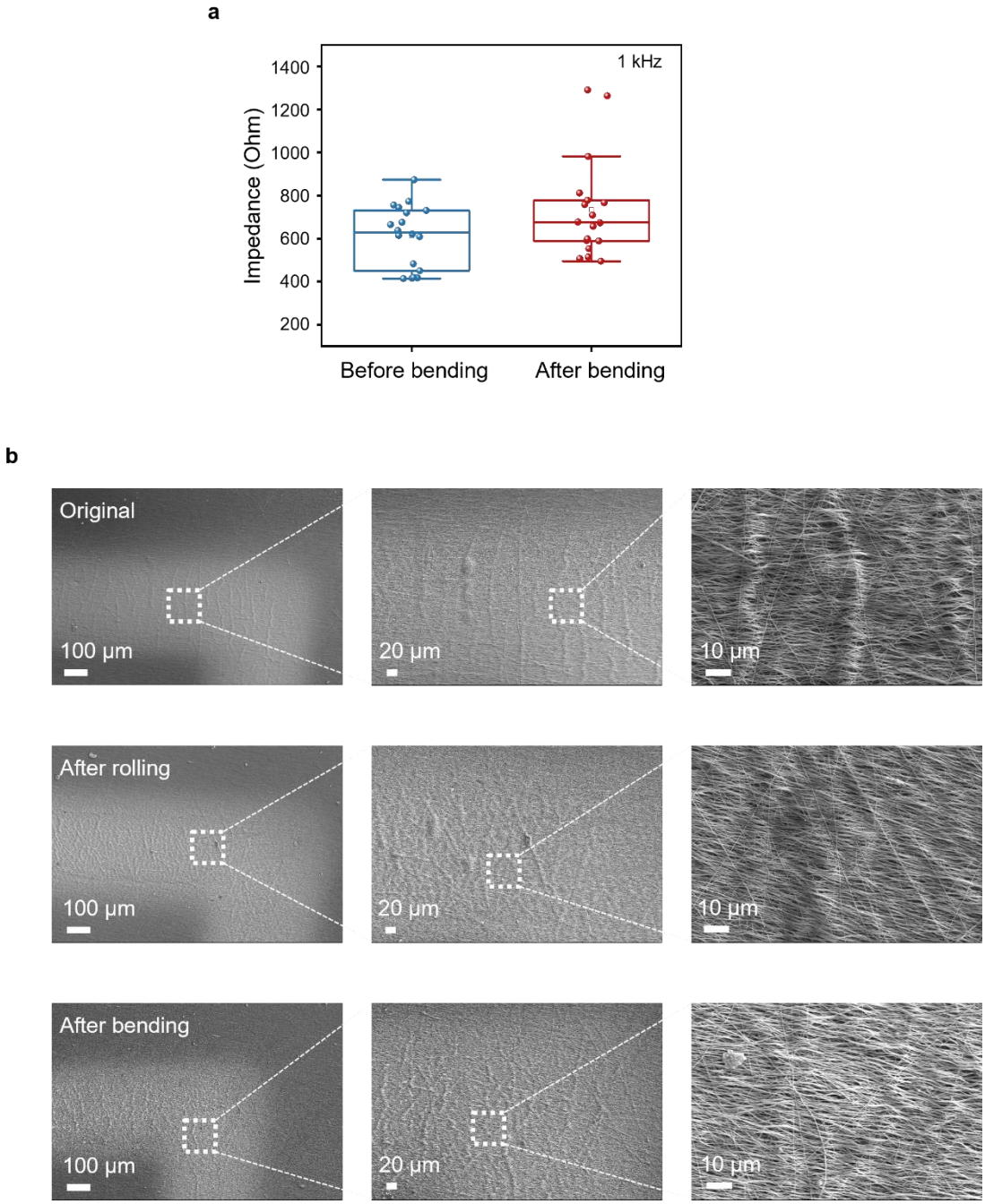
Supplementary Figure 4 | Effect of different concentrations of PCL solution on the diameter of electrospun fibers. a-f SEM images of 5%, 9%, 13%, 15%, 19%, 23% PCL fibers, respectively. **g** Statistical diagram of electrospun fiber diameters of different concentrations of PCL solution. n = 5 samples in each group. Data are presented as mean ± SD.

Supplementary Figure 5



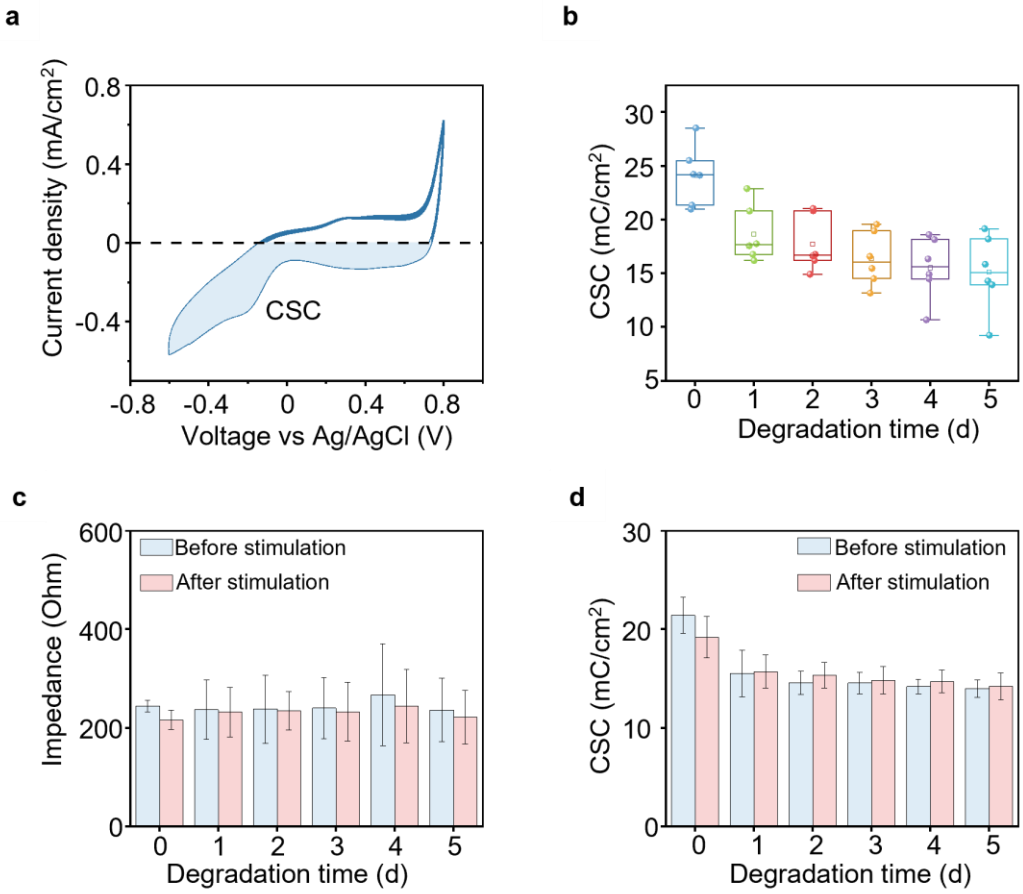
Supplementary Figure 5 | Detailed images of DRG (β-tubulin, green), Schwann cell (S100, red) and nuclei (DAPI, blue) growth on 5, 9, 13, 15% PCL after 7th day cell culture.

Supplementary Figure 6



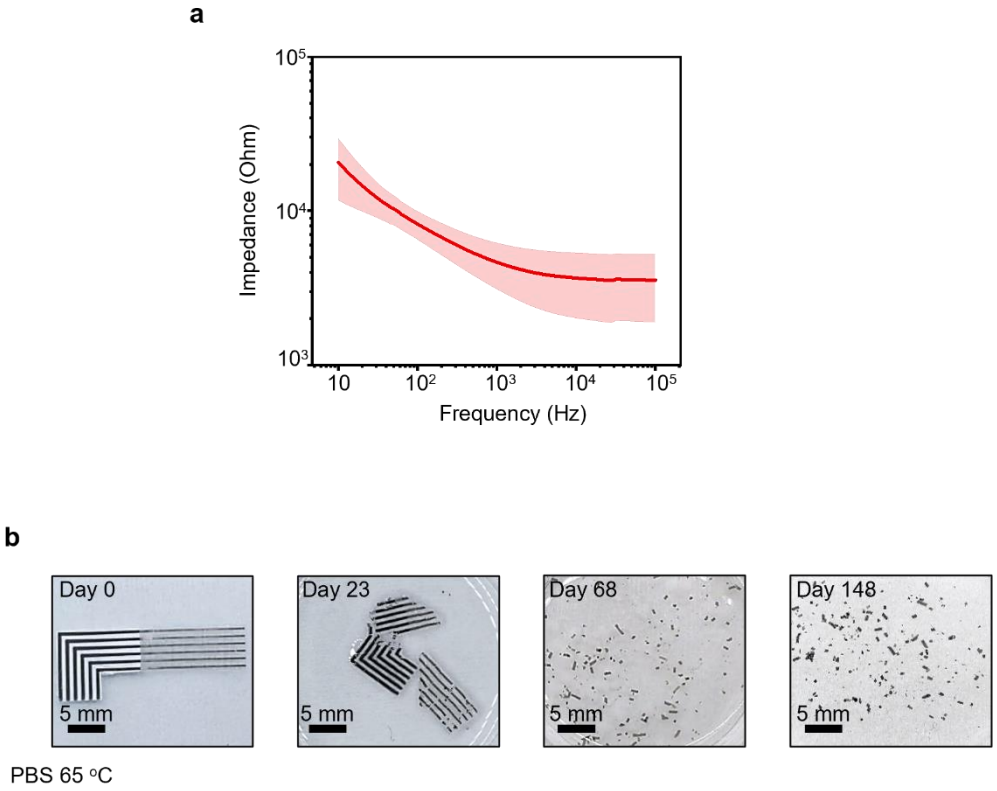
Supplementary Figure 6 | a The impedance at 1 kHz of the Au electrodes before and after cyclic bending 10000 times (bending radius: 5 mm, frequency: 1 Hz). n = 3 samples, with 6 microelectrodes in each sample. The box plot presents the median (center line), lower quartile (lower border), upper quartile (upper border), maximum (upper whisker) and minimum (lower whisker), which are ≤ 1.5 times the interquartile range. **b** SEM images of the device before and after rolling into the conduit and cyclic bending, respectively.

Supplementary Figure 7



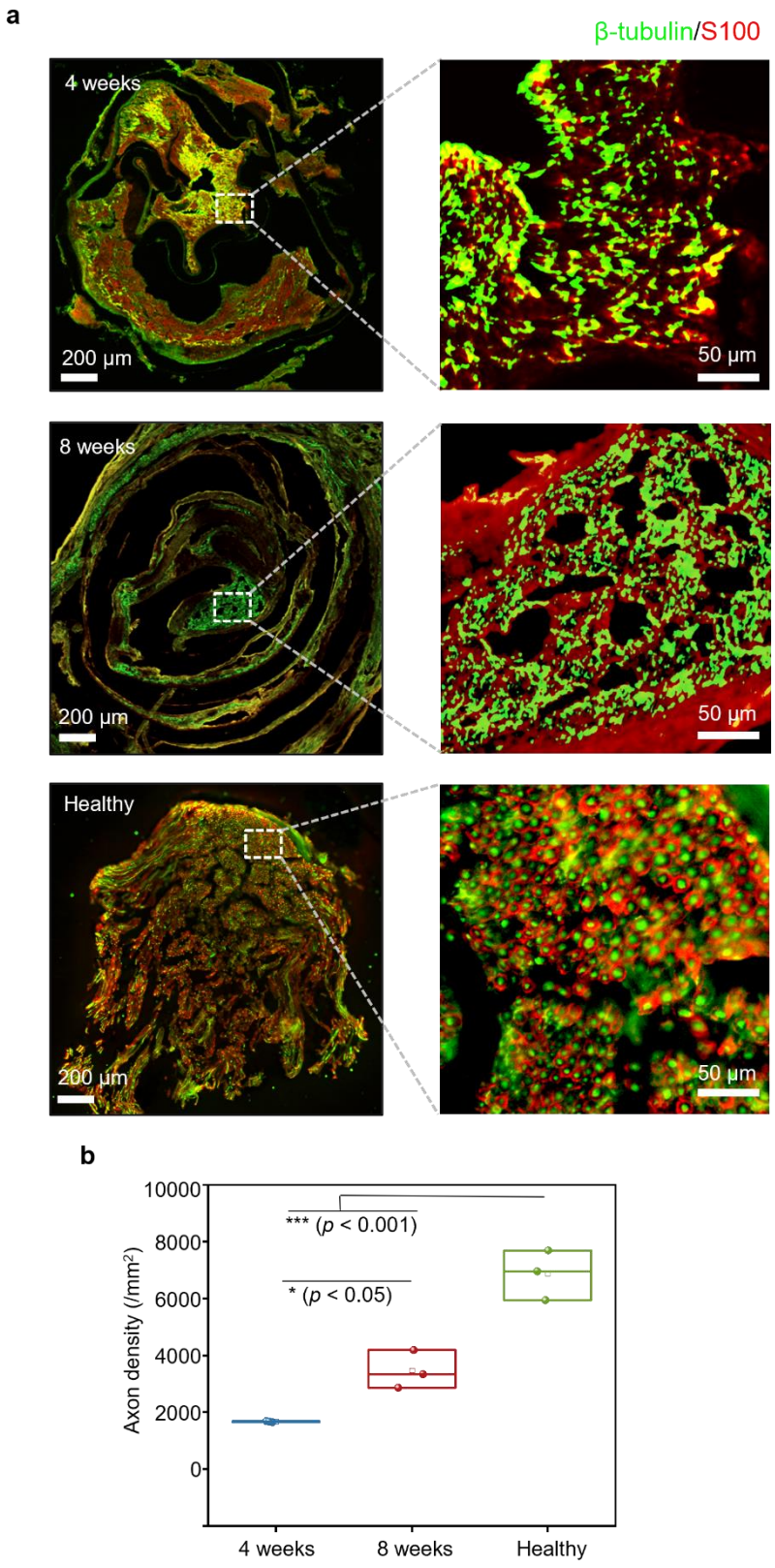
Supplementary Figure 7 | Electrochemical properties of NeuroSyn used for stimulation. a The representative CV curve of NeuroSyn. The colored area represents the cathodic charge storage capacity (CSC) of the device. **b** The CSC measured through CV curves after immersion in PBS (pH 7.4, 37 ºC) for 6 days. **c, d** The impedance (**c**) and CSC (**d**) of NeuroSyn after immersion in PBS (pH 7.4, 37 ºC) for 6 days and applying electrical stimulation each day. Stimulation parameters: pulse wave, 0.5 V, 20 Hz, pulse width1 ms, 1 h for a day. Data are presented as mean ± SD. In **a** to **d**, $n = 3$ devices. The box plot presents the median (center line), lower quartile (lower border), upper quartile (upper border), maximum (upper whisker) and minimum (lower whisker), which are ≤ 1.5 times the interquartile range.

Supplementary Figure 8



Supplementary Figure 8 | a The impedance of the Au electrodes (thickness = 30 nm). *n* = 3 samples, with 6 microelectrodes in each sample. Data are presented as mean ± SD. **b** Photo of the degradation process of the device (the thickness of Au is 30 nm) in PBS (pH 7.4, 65 ºC).

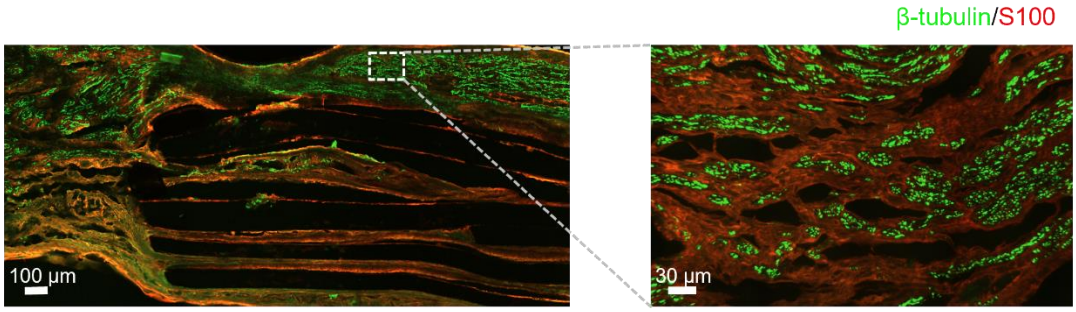
Supplementary Figure 9



Supplementary Figure 9 | Evaluations of regenerated nerve segments at 4 and 8 weeks post-implantation. a Immunofluorescent images of transverse section at 2 mm from the proximal end of the nerve segment at 4 and 8 weeks post-implantation

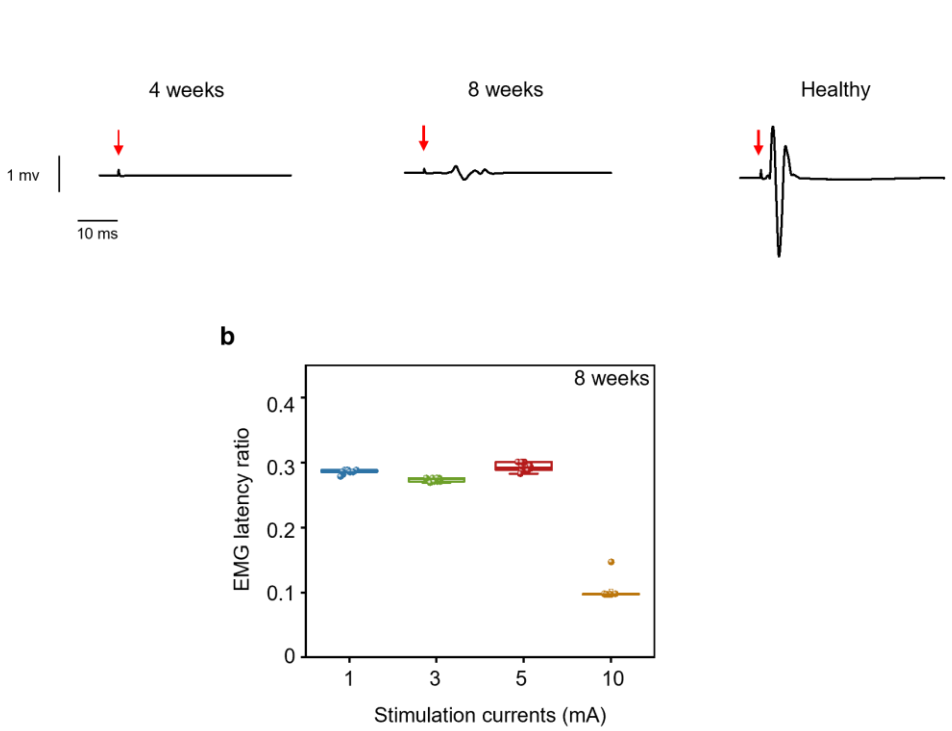
compared with the healthy nerve. **b** The axon density of the transverse sections at 2 mm from the proximal end of the nerve segment. The box plot presents the median (center line), lower quartile (lower border), upper quartile (upper border), maximum (upper whisker) and minimum (lower whisker), which are ≤ 1.5 times the interquartile range. Statistics is analyzed through SPSS (version 27.0), followed by one way ANOVA (*p < 0.05, **p < 0.01, ***p < 0.001). Tukey's post-hoc test is used for pairwise comparisons. Immunohistochemical staining: axons (β-tubulin, green), Schwann cells (S100, red)**.**

Supplementary Figure 10



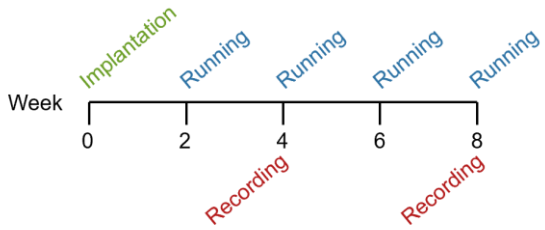
Supplementary Figure 10 | Immunofluorescent images of the longitudinal sections of regenerated nerve tissues at 8 weeks post-implantation. Immunohistochemical staining: axons (β-tubulin, green), Schwann cells (S100, red).

Supplementary Figure 11



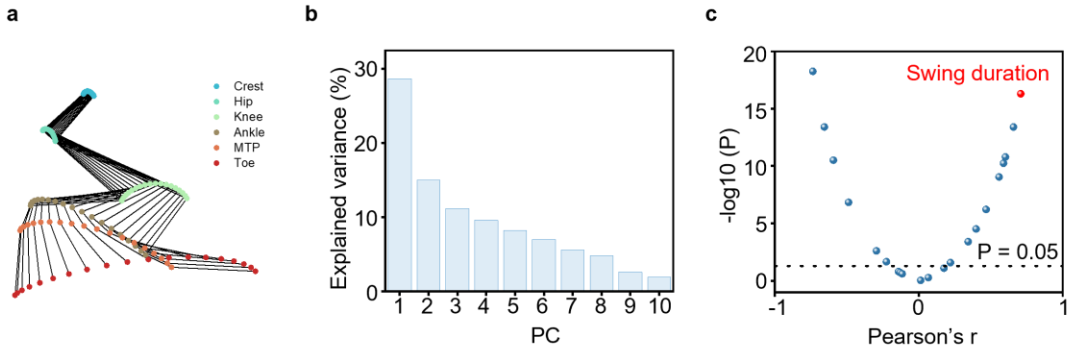
Supplementary Figure 11 | a Representative EMG traces evoked by commercial hook electrodes at 4 and 8 weeks post-implantation with a stimulation current of 5 mA. Red arrows indicate the point of stimulation. **b** The normalized EMG latency relative to contralateral control generated by different stimulation currents at the proximal side on the operated side at 8 weeks post-implantation. n = 5 animals in each group. The box plot presents the median (center line), lower quartile (lower border), upper quartile (upper border), maximum (upper whisker) and minimum (lower whisker), which are ≤ 1.5 times the interquartile range.

Supplementary Figure 12



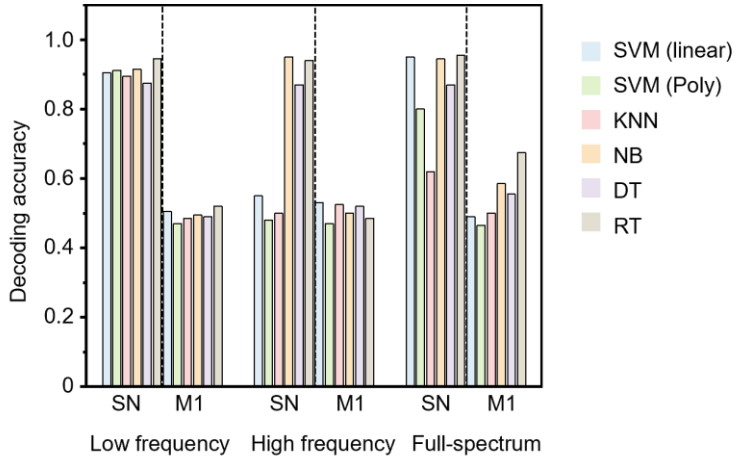
Supplementary Figure 12 | Schematic diagram of experiment time line.

Supplementary Figure 13



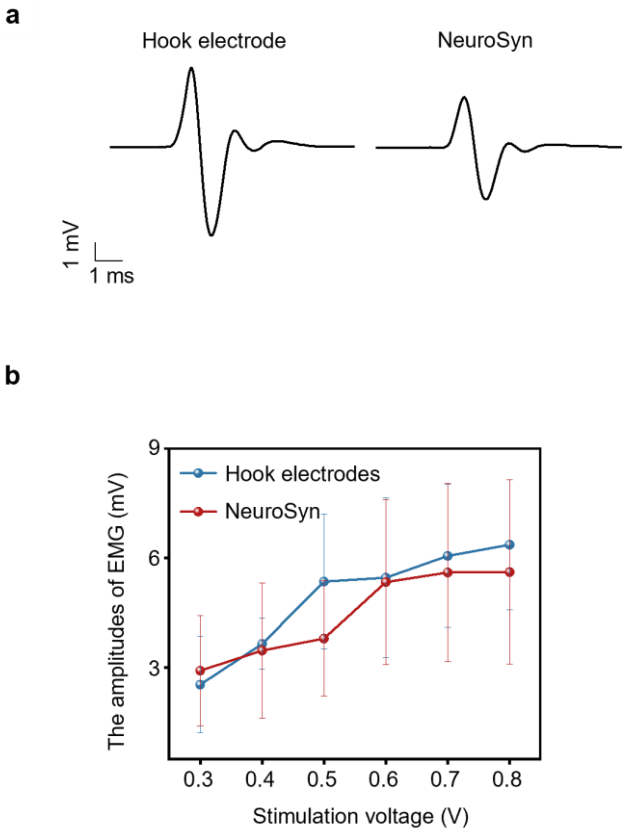
Supplementary Figure 13 | a Stick diagram illustrating leg movements of a healthy rat during treadmill walking. **b** Top 10 principal components variance of gait parameters. **c** Correlation between gait parameters and locomotion performance. The red point represents "swing duration", which exhibits the most consistent concordance with the progress of gait recovery.

Supplementary Figure 14



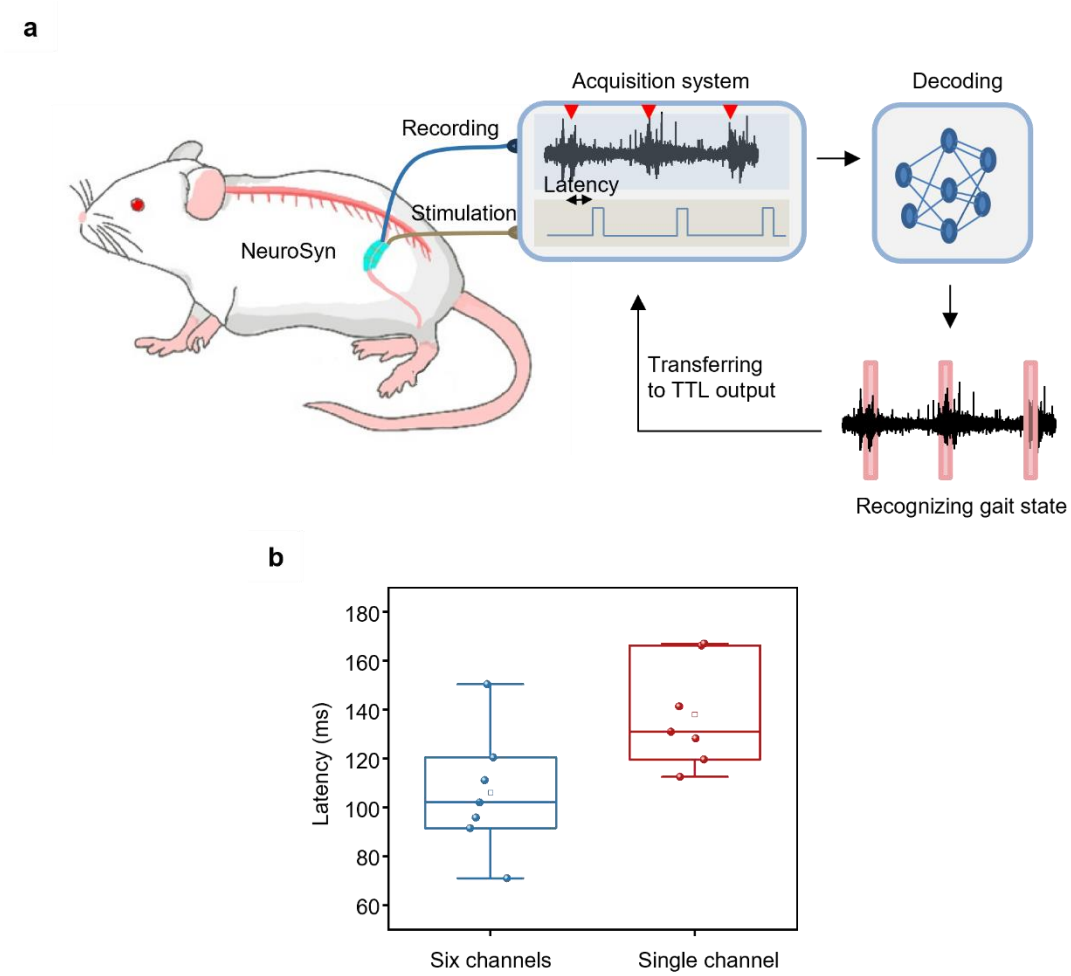
Supplementary Figure 14 | Decoding accuracy of different machine learning models among different frequencies. SVM (linear): Support vector machine (linear); SVM (Poly): Support vector machine (polynomial); KNN: K-nearest neighbors; NB: naive Bayes; DT: Decision tree; RT: Random tree.

Supplementary Figure 15



Supplementary Figure 15 | NeuroSyn for acute neural stimulation. a The representative EMG wave of the gastrocnemius muscle evoked by commercial bipolar hook electrodes and NeuroSyn. Stimulation parameters: 0.5 V, 20 Hz,1 ms. **b** The amplitude of the EMG signals increases with the rise in stimulation voltage. n = 3 animals. Data are presented as mean ± SD.

Supplementary Figure 16



Supplementary Figure 16 | A simulated latency analysis of the proposed closed-loop system. a Simulation of the closed-loop control, including acquiring sciatic nerve signals, decoding the signals, recognizing the gait state, transferring the signals to TTL output and sending stimulation to the nerve. The red triangle represents the swing onset. **b** Latency between the model-detected swing onset and the experimentally measured onset of hindlimb movement using data collected by NeuroSyn with different channels. The box plot presents the median (center line), lower quartile (lower border), upper quartile (upper border), maximum (upper whisker) and minimum (lower whisker), which are ≤ 1.5 times the interquartile range.

Supplementary Table 1

Supplementary Table 1| Total 21 gait parameters.

Parameter clusters	Parameters
Temporal gait features	Stance duration
	Swing duration
	Cycle duration
	Swing percentage
	Stance percentage
Limb trajectories	Stride length
	Cycle velocity
	Time of maximal velocity during swing
	Foot speed at swing onset
	Foot acceleration at swing onset
	Orientation of the velocity at swing onset
	Mean toe-to-crest distance
	Max toe-to-crest distance
	Min toe-to-crest distance
Joint angle	Knee joint extension
	Knee joint flexion
	Ankle joint extension
	Ankle joint flexion
Limb coordination	Correlation between hip and knee
	Correlation between knee and ankle
	Correlation between ankle and foot

Supplementary Table 2

Supplementary Table 2 | Comparisons of biodegradable peripheral nerve interface.

Applications	Material selection	Electrical stability	Animal model	Working lifetime	SNR	Decoding accuracy	Ref.
Monitoring and stimulation	Au/PCL/PLLA-PTMC	Z: 228.8 Ω at day 68 (PBS, 37 ºC) CSC: 15 mC/cm^2 at day 5	6 mm defect in rat's sciatic nerve	8 weeks	19.5 dB (week 8)	0.95	This work
Monitoring	Mo/PLLA-PTMC	86 kΩ at week 5 (PBS, 37 ºC)	10 mm defect in rat's sciatic nerve	3 weeks	N/A	0.85	34
	Pt/Tyrosine-derived Polycarbonate	~3.1 kΩ	Cut in rabbit's sciatic nerve	8 weeks	2 dB (week 8)	N/A	75
Stimulation	Mg/PHBV	Vpp: ~4V for 120 min	Crush on mice's sciatic nerve or C22 mice	5 days	N/A	N/A	76
	Mo/Mg/PA/PLGA	Z: ~55 Ω at week 2 (PBS, 37 ºC) CSC: 40 mC/cm^2 at week 2	Pain relief in rat's sciatic nerve	9 days	N/A	N/A	77