

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

- | | |
|-------------------------------------|--|
| n/a | Confirmed |
| ☐ | ☒ The exact sample size (<i>n</i>) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ A description of all covariates tested |
| ☒ | ☐ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☐ | ☒ For null hypothesis testing, the test statistic (e.g. <i>F</i> , <i>t</i> , <i>r</i>) with confidence intervals, effect sizes, degrees of freedom and <i>P</i> value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ Estimates of effect sizes (e.g. Cohen's <i>d</i> , Pearson's <i>r</i>), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection	The micromorphology characteristics were assessed utilizing SEM (Nova NanoSEM 230, Japan). The chemical states were characterized via XPS (Thermo Scientific ESCALAB 250Xi). The water contact angles were detected using a droplet shape analyzer (KRÜSS GmbH, Germany). A 3D optical profilometer (Leica DVM6, Leica) was used to measure the roughness of the hydrogels. The mechanical strength was measured using a universal tensile-compressive tester (2 kN, CMT1203). The CMT-1503 electromechanical tester (SUST Inc., China) was used to measure the hydrogel's lap-shear strength and interfacial toughness. Confocal images were collected with FluoView31S (ver.2.3.1.163).
Data analysis	Gaussian 16 software was used to calculate DFT. Statistical analysis was performed with Origin 2021(ver. 9.80.200).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

All data supporting the findings of this study are available within the article, supplementary information, or Source Data file. Any additional requests for information can be directed to and will be fulfilled by the corresponding authors. Source data are provided with this paper.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender

Reporting on race, ethnicity, or other socially relevant groupings

Population characteristics

Recruitment

Ethics oversight

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☒ Life sciences ☐ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

Sample size

Data exclusions

Replication

Randomization

Blinding

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☐	☒ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☐	☒ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Eukaryotic cell lines

Policy information about [cell lines and Sex and Gender in Research](#)

Cell line source(s)	Mouse Fibroblasts L-929 (L929) (catalog number: KGG1306-1) and Mouse Monocyte-Macrophage Leukemia Cells (RAW264.7) (catalog number: KGG2201-1) were obtained from Jiangsu Kaiji Biotechnology Co., Ltd.
Authentication	L929, RAW 264.7 cell lines were authenticated using Short Tandem Repeat (STR) analysis
Mycoplasma contamination	All cell lines were tested mycoplasma-negative using a DNA-based PCR test.
Commonly misidentified lines (See ICLAC register)	No commonly misidentified cell lines were used in this study.

Animals and other research organisms

Policy information about [studies involving animals](#); [ARRIVE guidelines](#) recommended for reporting animal research, and [Sex and Gender in Research](#)

Laboratory animals	Institute of Cancer Research (ICR) mice (female, 25 - 35 g, 6-8 weeks), Sprague-Dawley (SD) rat (male, 200-230 g, 6-8 weeks), and Sprague-Dawley (SD) rat (female, 200-230 g, 6-8 weeks) were purchased from Zhuhai Baishi Tong Biotechnology Co., Ltd. Bama mini pigs (male, 25-30 kg, 8 months) were purchased from Guangzhou Liming Biotechnology Co., Ltd.
Wild animals	The study did not involve wild animals.
Reporting on sex	The subcutaneous implantation experiment was conducted using female ICR mice. The hemostasis experiment was conducted using male SD rats and male bama pigs. The intestinal injury experiment was conducted using male SD rats. The uterine injury experiment was conducted using female SD rats.
Field-collected samples	This study did not involve samples collected from the field.
Ethics oversight	The animal experiment on mice and rats was approved by the Institutional Animal Care Committee of Guangzhou Medical University Laboratory Animal Center (Approval No.GY2025-025). The animal experiment on pigs was approved by the Institutional Animal Care Committee of Guangzhou Liming Biotechnology Co., Ltd. (Approval No.2025008).

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Plants

Seed stocks	N/A
Novel plant genotypes	N/A
Authentication	N/A