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Last updated by author(s): Oct 31, 2025

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 (n) 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
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☒ ☐ 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. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
Give P values as exact values whenever suitable.
- ☒ ☐ 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 d , Pearson's r), 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

IH NMR spectra were collected with MestReNova Software (Ver.14.0). TEM images were collected with NanoScope Analysis (Ver.1S). N₂ adsorption isotherms were collected with a JW-DX Surface Area Analyzer at −196 °C. All the samples were pre-treated under 100 °C for 12 h before measurements. Thermogravimetric analyses (TGA) were performed under N₂ atmosphere (20 mL min^{−1}) with temperature increasing at 10 °C min^{−1} using a TA-Q50 system. The samples were dried in vacuo at 100 °C for 12 h before TGA analysis. Powder X-ray diffraction (PXRD) patterns were collected (0.02°/step, 0.06 seconds/step) on a Bruker D8 Advance diffractometer (Cu K α) at room temperature. The hydrodynamic diameter, size distribution of nanoparticles, and zeta potentials of nanoparticles were measured using the Zeta-Nanosizer (ZEN3600, Malvern Instruments Ltd, Worcestershire, UK), which was routinely calibrated with a -50 mV Zeta-potential standard (Malvern Instruments). Drug release behaviors were recorded by a fluorospectrophotometer (F-7100, Hitachi High-Tech Co., Ltd., Tokyo, Japan) at an excitation wavelength of 495 nm and an emission wavelength of 595 nm, or measured by high-performance liquid chromatography (HPLC) using an Agilent Technologies 1260 Infinity II (Agilent Technologies, USA) equipped with a C18 column (4.6 × 250 mm, 5 μ m, Welch). Flow cytometric data was collected with NovoExpress (Ver.1.4). In vivo images were collected with Bruker MI SE (Ver.7.2). MRI were collected with a 3-T clinical MR scanner (Achieva, Philips Medical Systems, Best, The Netherlands) equipped with a 50-mm small animal coil (Zhongzhi Medical Technologies, Suzhou, China), T₂-weighted images were then acquired.

Data analysis

Statistical analyses were performed on GraphPad Prism 10.0, flow cytometry data were analyzed on NovoExpress (Ver.1.4) and FlowJo 10.8.1, images were processed with Image J software (Ver.1.5).

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](#)

The figures of NMR spectra are summarized in Fig.2a in the Article and Supplementary Figs. 2, and 3 in the Supplementary Information and the Source Data file. All data supporting the findings of this study are available within the Article, Supplementary Information, or Source Data file. Source data are provided within 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	n/a
Reporting on race, ethnicity, or other socially relevant groupings	n/a
Population characteristics	n/a
Recruitment	n/a
Ethics oversight	n/a

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	The sample size (n>=3) of each experiment is included in the corresponding figure legends. In the survival experiment, at least 5 mice per group were used. Sample sizes were chosen to ensure reproducibility of the experiments in accordance with the replacement, reduction and refinement principles of animal ethics regulation.
Data exclusions	No data were excluded.
Replication	All experimental results were reliably reproduced. The in vitro data were performed at least 3 times. For the in vivo imaging, at least 3 mice per group were used. In the anti-tumor efficacy studies, at least 5 mice per group were used. Details of experimental replicates are given in the figure legends.
Randomization	All samples were randomly allocated into experimental groups.
Blinding	Investigators were not blinded to group allocation. Because most of the experiments needed multiple treatments, the investigators should keep careful track of protocols. Therefore, it would be difficult to blind the investigators to group allocation during the experiments.

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

Antibodies

Antibodies used

The anti-PD-1 antibody (rat anti-mouse) (Cat#135202, Clone#29F.1A12), anti-mouse CD8 antibody (Alexa Fluor®647-labeled) (Cat#100727, Clone#53-6.7), Anti-mouse CD3 antibody (APC conjugated) (Cat#100236, Clone#17A2), Anti-mouse CD4 antibody (PE-Cy7 conjugated) (Cat#100422, Clone#GK1.5), Anti-mouse CD8 antibody (APC-Cy7 conjugated) (Cat#100714, Clone#53-6.7), Anti-mouse intracellular IFN-γ antibody (PE conjugated) (Cat#505807, Clone#XMG1.2), Anti-mouse CD366 (Tim3) antibody (PE conjugated) (Cat#119703, Clone#RMT3-23), Anti-mouse CD279 (PD-1) antibody (PerCP/Cyanine5.5 conjugated) (Cat#135207, Clone#29F.1A12) were purchased from Biolegend Inc (San Diego, CA, USA). The anti-CD8 alpha antibody (rabbit monoclonal antibody) (ab209775, Clone#EPR20305), Anti-Granzyme B antibody (rabbit polyclonal antibody) (ab4059), Anti-Interferon gamma antibody (rabbit polyclonal antibody) (ab9657), Anti-CD3 antibody (rat monoclonal antibody) (ab11089, Clone#CD3-12), Anti-RANTES (CCL5) antibody (rabbit monoclonal antibody) (ab322195, Clone#EPR25836-32), Anti-GAPDH antibody (rabbit monoclonal antibody) (ab181602, Clone#EPR16891), Goat Anti-Rat IgG H&L (Alexa Fluor® 555) (ab150158), Goat Anti-Rabbit IgG H&L (Alexa Fluor® 488) (ab150077) were purchased from Abcam (Cambridge, United Kingdom). The hyaluronic acid antibody (rabbit polyclonal antibody) (abx101090) was purchased from Abbexa (Cambridge, UK). The goat anti-rabbit IgG antibody (HRP) (ARG65351) was purchased from purchased from Arigo Biolaboratory (Taiwan, China).

Validation

All antibodies were verified by the supplier and each has been quality tested. All validation statements are available on the antibody websites.

1. Anti-PD-1 antibody (rat anti-mouse): <https://www.biolegend.com/en-us/products/purified-anti-mouse-cd279-pd-1-antibody-6167>
2. Alexa Fluor®647-labeled anti-mouse CD8 antibody: <https://www.biolegend.com/en-ie/products/alexa-fluor-647-anti-mouse-cd8a-antibody-2699>
3. Anti-mouse CD3 antibody (APC conjugated): <https://www.biolegend.com/en-us/products/apc-anti-mouse-cd3-antibody-8055>
4. Anti-mouse CD4 antibody (PE-Cy7 conjugated): <https://www.biolegend.com/en-us/products/pe-cyanine7-anti-mouse-cd4-antibody-1919>
5. Anti-mouse CD8 antibody (APC-Cy7 conjugated): <https://www.biolegend.com/en-us/products/apc-cyanine7-anti-mouse-cd8a-antibody-2269>
6. Anti-mouse intracellular IFN-γ antibody (PE conjugated): <https://www.biolegend.com/en-us/products/pe-anti-mouse-ifn-gamma-antibody-997>
7. Anti-CD8 alpha antibody (rabbit monoclonal antibody): <https://www.abcam.com/en-us/products/primary-antibodies/cd8-alpha-antibody-epr20305-ab209775>
8. Anti-Granzyme B antibody (rabbit polyclonal antibody): <https://www.abcam.com/en-us/products/primary-antibodies/granzyme-b-antibody-ab4059>
9. Anti-Interferon gamma antibody (rabbit polyclonal antibody): <https://www.abcam.com/en-us/products/primary-antibodies/interferon-gamma-antibody-ab9657>
10. Anti-CD3 antibody (rat monoclonal antibody): <https://www.abcam.com/en-us/products/primary-antibodies/cd3-antibody-cd3-12-ab11089>
11. Goat Anti-Rat IgG H&L (Alexa Fluor® 555): <https://www.abcam.com/en-us/products/secondary-antibodies/goat-rat-igg-h-l-alexa-fluor-555-ab150158>
12. Goat Anti-Rabbit IgG H&L (Alexa Fluor® 488): <https://www.abcam.com/en-us/products/secondary-antibodies/goat-rabbit-igg-h-l-alexa-fluor-488-ab150077>
13. Hyaluronic acid antibody (rabbit polyclonal antibody): <https://www.abbexa.com/hyaluronic-acid-antibody>
14. Goat anti-rabbit IgG antibody (HRP): <https://www.arigobio.com/Goat-anti-Rabbit-IgG-antibody-HRP-ARG65351.html>
15. Anti-mouse CD366 (Tim3) antibody (PE conjugated): <https://www.biolegend.com/en-gb/products/pe-anti-mouse-cd366-tim-3-antibody-2657>
16. Anti-mouse CD279 (PD-1) antibody (PerCP/Cyanine5.5 conjugated) : <https://www.biolegend.com/en-gb/products/percp-cyanine5-5-anti-mouse-cd279-pd-1-antibody-6496>
17. Anti-RANTES (CCL5) antibody (rabbit monoclonal antibody): <https://www.abcam.cn/products/primary-antibodies/rantes-antibody-epr25836-32-ab322195>
18. Anti-GAPDH antibody (rabbit monoclonal antibody): <https://www.abcam.cn/products/primary-antibodies/gapdh-antibody-epr16891-loading-control-ab181602>

Eukaryotic cell lines

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

Cell line source(s)

The mice pancreatic cancer cells (Panc02, Catalog No.CL-0736) and luciferase protein gene recombinant mice pancreatic cancer cells (Panc02-Luc) were purchased from Wuhan Pricella Biotechnology Co., Ltd (Wuhang, China).

Authentication	None of the cell lines used were authenticated.
Mycoplasma contamination	All cell lines were tested negative for mycoplasma contamination by using MycAway™-Color One-Step Mycoplasma Detection Kit.
Commonly misidentified lines (See ICLAC register)	No commonly misidentified cell lines were used.

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	Four-week-old immunodeficient male NOD-Prkdcem26Cd52Il2rgem26Cd22/Nju (NCG) mice were purchased from the GemPharmatech Co., Ltd, four-week-old male or female C57BL/6j mice were purchased from Guangdong Medical Laboratory Animal Center. All animals were carefully housed in specific pathogen-free (SPF) environment, and subjected to regulated environmental conditions, including a precisely maintained temperature of 22°C humidity levels ranging between 40% and 50%, and a strictly adhered to light/dark cycle of 12 h each, with unrestricted access to both water and food.
Wild animals	No wild animal was used in this study.
Reporting on sex	The experiment was designed without considering the sex of the animals, both male and female mice were used in studies.
Field-collected samples	No field collected samples were involved in this study.
Ethics oversight	All surgical procedures and postoperative care protocols received prior approval from the Institutional Animal Care and Use Committee of Sun Yat-sen University, Guangzhou, China. The assigned approval number of the ethical application of animal experiments is SYSU-IACUC-2023-001684.

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

Flow Cytometry

Plots

Confirm that:

- ☐ The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).
- ☐ The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).
- ☒ All plots are contour plots with outliers or pseudocolor plots.
- ☒ A numerical value for number of cells or percentage (with statistics) is provided.

Methodology

Sample preparation	Adherent cells were trypsinized, harvested and washed with PBS for three time. The tissue was undergone mechanical dissociation and enzymatic digestion to prepare the single-cell suspension. In some experiments, cells were pre-treated with CD16/32 antibody according to the manufacturer's protocols, and then stained with fluorescently labeled antibodies.
Instrument	NovoCyte 3000 (Agilent Technologies, USA).
Software	NovoExpress (Ver.1.4).
Cell population abundance	No cell sorting was performed.

Gating strategy

Cells were gated by FSC/SSC gates for cell population. The FSC-h/FSC-A plots was used to isolate single cells.

☒ Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.