nature portfolio

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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	TEM and high-resolution TEM (HR-TEM): FEI Talos F200X G2 (Thermo Fisher); Ultraviolet-visible (UV-Vis) absorption spectra: UV-vis spectrophotometer (Lambda 950, Perkin Elmer); AFM: Dimension XR Fast Scan (Bruker); DLS and zeta potential: particle size analyzer (Nano-ZS); Circular dichroism: Chirascan VX (Applied Photophysics); Thermal imaging camera: FLuke Ti27; In-vivo Imaging: IVIS Spectrum System (Perkin Elmer); Flow cytometry: Cytek NL-CLC3000; Immunohistochemical and immunofluorescence imaging: 3DHISTECH; Western blotting imaging: ImageQuant LAS 500 (GE)
Data analysis	Statistical analyses were performed using GraphPad Prism software. FlowJo was used to process all the flow cytometry data. LivingImage software was used to process mouse images. SmartView was used to process photothermal images. ImageJ was used to process all the western blotting, immunohistochemical and immunofluorescence images.

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

Data Availability. The authors declare that all the data supporting the findings of this study are available within the article and its Supplementary Information files or from the corresponding author upon reasonable request.

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

Life sciences study design

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

Sample size	Sample size determination was based on statistical requirements and journal guidelines to ensure statistical significance and reproducibility. In relapse experiments, a larger sample size was used: for subcutaneous mouse tumor models, n = 20 per group, and for patient-derived xenograft (PDX) models, n = 8 per group. In the in vivo antitumor study, each group included at least 5 animals ($n \geq 5$) to assess statistical significance, while for in vivo immune response evaluations, a minimum of 3 animals per group ($n \geq 3$) was used. For in vitro experiments, biodistribution studies, and in vivo photothermal performance, a sample size of $n \geq 3$ was selected to provide an accurate estimate of the true effect while minimizing costs. The exact sample size for each experiment is specified in the figure legends. Sample size was determined with consideration of animal variability and adherence to the 4R principles to ensure the robustness and reliability of the results.
Data exclusions	No data were excluded from the analyses.
Replication	All experiments underlying main conclusions of this study have been successfully replicated multiple times and corroborated by several models.
Randomization	All samples/organisms were randomly allocated into experimental groups.
Blinding	The investigators were blinded to group allocation during data collection and analysis.

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 following antibody was used for in vivo PD-L1 blockade and treatment. It is listed as antigen first, followed by supplier, catalog number and clone/lot number as applicable.
1) InVivo anti-mouse PD-L1 (B7-H1) (BioXCell, mAb, #BE0101)

The following antibodies were used for western blotting. They are listed as antigen first, followed by supplier, catalog number and clone/lot number as applicable.
1) Anti-HSP70 antibody (Servicebio, Rabbit pAb, GB11241, 1:1000 dilution)
2) Anti-p-mTOR antibody (Abclonal, Rabbit mAb, AP0115, 1:1000 diltution)
3) Anti-mTOR antibody (Abclonal, Rabbit pAb, A23168, 1:1000 diltution)
4) Anti-p-P70S6K antibody (Abclonal, Rabbit mAb, AP1389, 1:1000 diltution)
5) Anti-P70S6K antibody (Abclonal, Rabbit mAb, A4898, 1:1000 diltution)
6) Anti-p-S6 antibody (Abclonal, Rabbit pAb, AP0538, 1:1000 diltution)
7) Anti-S6 antibody (Abclonal, Rabbit mAb, A11874, 1:1000 diltution)
8) Anti-p-4EBP1 antibody (Abclonal, Rabbit mAb, AP1363, 1:1000 diltution)
9) Anti-4EBP1 antibody (Abclonal, Rabbit mAb, A24691, 1:1000 diltution)
10) Anti-p-AKT antibody (Abclonal, Rabbit mAb, AP0637, 1:1000 diltution)
11) Anti-AKT antibody (Servicebio, Rabbit pAb, GB13427, 1:1000 dilution)
12) Anti-Actin antibody (Servicebio, Mouse mAb, GB15001, 1:3000 dilution)
13) HRP conjugated Goat Anti-Rabbit IgG (Servicebio, GB23303, 1:10000 dilution)
14) HRP conjugated Goat Anti-Mouse IgG (Servicebio, GB23301, 1:10000 dilution)

The following antibodies were used for immumohistochemical staining and immunofluorescence staining. They are listed as antigen first, followed by supplier, catalog number and clone/lot number as applicable.
1) Anti-Calreticulin (CRT) antibody (Servicebio, Rabbit pAb, GB112134, 1:250 dilution)
2) Anti-HSP70 antibody (Servicebio, Rabbit pAb, GB11241, 1:500 dilution)
3) Anti-HMGB1 antibody (Servicebio, Rabbit pAb, GB11103, 1:300 dilution)
4) Anti-Cleaved caspase-3 (Servicebio, Rabbit pAb, GB11532, 1:500 dilution)
5) Anti-Ki67 (Servicebio, Mouse mAb, GB121141, 1:300 dilution)
6) HRP conjugated Goat Anti-Rabbit IgG (Servicebio, GB23303, 1:1000 dilution)
7) HRP conjugated Goat Anti-Mouse IgG (Servicebio, GB23301, 1:1000 dilution)
8) Cy3-conjugated goat anti-rabbit IgG (Servicebio, GB21303, 1:300 dilution)
9) Alexa Fluor® 488-conjugated goat anti-rabbit IgG (Servicebio, GB25303, 1:300 dilution)

The following antibodies were used for flow cytometry. They are listed as antigen first, followed by supplier, catalog number and clone/lot number as applicable.
1) BB515 rat anti-mouse CD45 antibody (BD, 564590, 1:100 dilution)
2) APC/Fire™ 750 anti-mouse CD3 antibody (BioLegend, 100248, 1:100 dilution)
3) APC anti-mouse CD4 antibody (BioLegend, 100412, 1:100 dilution)
4) PE/Cyanine7 anti-mouse CD8a antibody (BioLegend, 100722, 1:100 dilution)
5) APC/Cyanine7 anti-mouse CD11c antibody (BioLegend, 117324, 1:100 dilution)
6) PE anti-mouse CD80 antibody (BioLegend, 104708, 1:100 dilution)
7) Brilliant Violet 421™ anti-mouse CD86 antibody (BioLegend, 105032, 1:100 dilution)
8) APC anti-mouse I-A/I-E antibody (BioLegend, 107614, 1:100 dilution)
9) PE anti-mouse/human CD11b antibody (BioLegend, 101208, 1:100 dilution)
10) PE/Cyanine7 anti-mouse Ly-6G/Ly-6C (Gr-1) antibody (BioLegend, 108416, 1:100 dilution)
11) PE anti-mouse CD25 antibody (BioLegend, 102007, 1:100 dilution)
12) FOXP3 monoclonal antibody (FJK-16s), PerCP-Cyanine5.5 (Thermo Fisher Scientific, 45-5773-82, 1:100 dilution)
13) PE/Cyanine7 anti-mouse/human CD44 antibody (BioLegend, 103030, 1:100 dilution)
14) APC anti-mouse CD62L antibody (BioLegend, 104412, 1:100 dilution)
15) PE anti-mouse CD4 antibody (BioLegend, 116005, 1:100 dilution)
16) TruStain FcX™ (anti-mouse CD16/32) antibody (Biolegend, 101320, 1:100 dilution)

Validation

All antibodies were verified by the supplier and have been quality tested. All validation statements can be found in the respective antibody website:
1) InVivo anti-mouse PD-L1 (B7-H1): https://bioxcell.com/invivomab-anti-mouse-pd-l1-b7-h1-be0101

2) Anti-HSP70 antibody: https://www.servicebio.cn/goodsdetail?id=1465
3) Anti-p-mTOR antibody: https://abclonal.com.cn/catalog/AP0115
4) Anti-mTOR antibody: A23168 is currently discontinued.
5) Anti-p-P70S6K antibody: https://abclonal.com.cn/catalog/AP1389
6) Anti-P70S6K antibody: https://abclonal.com.cn/catalog/A4898
7) Anti-p-S6 antibody: https://abclonal.com.cn/catalog/AP0538
8) Anti-S6 antibody: https://abclonal.com.cn/catalog/A11874
9) Anti-p-4EBP1 antibody: https://abclonal.com.cn/catalog/AP1363
10) Anti-4EBP1 antibody: https://abclonal.com.cn/catalog/A24691
11) Anti-p-AKT antibody: https://abclonal.com.cn/catalog/AP0637
12) Anti-AKT antibody: https://www.servicebio.cn/goodsdetail?id=5144
13) Anti-Actin antibody: https://www.servicebio.cn/goodsdetail?id=6718
14) HRP conjugated Goat Anti-Rabbit IgG: https://www.servicebio.cn/goodsdetail?id=266
15) HRP conjugated Goat Anti-Mouse IgG: https://www.servicebio.cn/goodsdetail?id=264
16) Anti-Calreticulin (CRT) antibody: https://www.servicebio.cn/goodsdetail?id=5108
17) Anti-HMGB1 antibody: https://www.servicebio.cn/goodsdetail?id=1383
18) Anti-Cleaved caspase-3 antibody: https://www.servicebio.cn/goodsdetail?id=1271
19) Anti-Ki67 antibody: https://www.servicebio.cn/goodsdetail?id=6801
20) Cy3-conjugated goat anti-rabbit IgG: https://www.servicebio.cn/goodsdetail?id=253
21) Alexa Fluor® 488-conjugated goat anti-rabbit IgG: https://www.servicebio.cn/goodsdetail?id=273
22) BB515 rat anti-mouse CD45 antibody: https://www.bdbiosciences.com/zh-cn/products/reagents/flow-cytometry-reagents/research-reagents/single-color-antibodies-ruo/bb515-rat-anti-mouse-cd45.564590
23) APC/Fire™ 750 anti-mouse CD3 antibody: https://www.biolegend.com/en-gb/products/apc-fire-750-anti-mouse-cd3-antibody-13052
24) APC anti-mouse CD4 antibody: https://www.biolegend.com/en-gb/products/apc-anti-mouse-cd4-antibody-245
25) PE/Cyanine7 anti-mouse CD8a antibody: https://www.biolegend.com/en-gb/products/pe-cyanine7-anti-mouse-cd8a-antibody-1906
26) APC/Cyanine7 anti-mouse CD11c antibody: https://www.biolegend.com/en-gb/products/apc-cyanine7-anti-mouse-cd11c-antibody-3931
27) PE anti-mouse CD80 antibody: https://www.biolegend.com/en-gb/products/pe-anti-mouse-cd80-antibody-43
28) Brilliant Violet 421™ anti-mouse CD86 antibody: https://www.biolegend.com/en-gb/products/brilliant-violet-421-anti-mouse-cd86-antibody-7282
29) APC anti-mouse I-A/I-E antibody: https://www.biolegend.com/en-gb/products/apc-anti-mouse-i-a-i-e-antibody-2488
30) PE anti-mouse/human CD11b antibody: https://www.biolegend.com/en-gb/products/pe-anti-mouse-human-cd11b-antibody-349
31) PE/Cyanine7 anti-mouse Ly-6G/Ly-6C (Gr-1) antibody: https://www.biolegend.com/en-us/products/pe-cyanine7-anti-mouse-ly-6g-ly-6c-gr-1-antibody-1931
32) PE anti-mouse CD25 antibody: https://www.biolegend.com/en-gb/products/pe-anti-mouse-cd25-antibody-424
33) FOXP3 monoclonal antibody (FJK-16s), PerCP-Cyanine5.5: https://www.thermofisher.cn/cn/zh/antibody/product/FOXP3-Antibody-clone-FJK-16s-Monoclonal/45-5773-82
34) PE/Cyanine7 anti-mouse/human CD44 antibody: https://www.biolegend.com/en-gb/products/pe-cyanine7-anti-mouse-human-cd44-antibody-3932
35) APC anti-mouse CD62L antibody: https://www.biolegend.com/en-gb/products/apc-anti-mouse-cd62l-antibody-381
36) PE anti-mouse CD4 antibody: https://www.biolegend.com/en-gb/products/pe-anti-mouse-cd4-antibody-2499
37) TruStain FcX™ (anti-mouse CD16/32) antibody: https://www.biolegend.com/en-gb/products/trustain-fcx-anti-mouse-cd16-32-antibody-5683

Eukaryotic cell lines

Policy information about cell lines and Sex and Gender in Research

Cell line source(s)	CT26-Luc cells (luciferase-expressing mouse colorectal cancer cells) were sourced from the Key Laboratory of Molecular Imaging, Institute of Automation, Chinese Academy of Sciences (Beijing, China).
Authentication	The cell lines used in this study have been authenticated by STR (Short Tandem Repeat) profiling, with certification reports from accredited institutions.
Mycoplasma contamination	Cells were routinely screened for free of Mycoplasma contaminations. All cell lines are Mycoplasma negative with this study.
Commonly misidentified lines (See ICLAC register)	No commonly misidentified cell lines were used in the 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	BALB/c mice and NTG mice (NOD-scid IL2Rγ −/−), both 6 weeks old, were obtained from SPF Biotechnology Co. Ltd. (Beijing, China). Animals were kept in a specific pathogen-free (SPF) environment at 20 ± 3 °C with a 12-hour light/dark cycle and free access to food and water. Animal procedures followed the guidelines for ethical research use set by Peking Union Medical College Hospital.
Wild animals	The study did not involve wild animals.

Reporting on sex	This study did not involve sex.
Field-collected samples	This study did not involve field-collected samples.
Ethics oversight	Animal procedures followed the guidelines for ethical research use set by Peking Union Medical College Hospital (permit number: XHDW-2022-016).

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

Plants

Seed stocks	This study did not involve seed stocks.
Novel plant genotypes	This study did not involve novel plant genotypes.
Authentication	This study did not involve the authentication of plants.

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	Tumor-infiltrating immune cells and spleen single cells were isolated and prepared as follows: After anesthetizing and euthanizing the mice, tumor tissues were excised and placed in sterile PBS containing 5% FBS. The tissues were weighed, minced with surgical scissors, and digested with a digestion solution (5 times the tissue volume) containing 10% FBS, 0.5 mg/mL Collagenase IV, 0.15 mg/mL DNase I, and RPMI 1640 at 37°C for 1 h, with gentle shaking every 10 min. After digestion, 10 mL of RPMI 1640 medium with 10% FBS was added to terminate the digestion. The mixture was centrifuged at 300g for 5 min, and the resulting pellet was resuspended in RPMI 1640 containing 10% FBS and filtered through a 70 µm cell strainer to remove large tissue fragments. The suspension was then centrifuged again at 300g for 5 min, and the pellet was resuspended in PBS containing 1% FBS, with the final cell concentration adjusted to 10^7 cells/mL for subsequent analysis. For spleen single-cell preparation, the spleen was excised under sterile conditions, and any surrounding fat tissue was removed. The spleen was placed in sterile PBS containing 5% FBS and minced in a Petri dish. The tissue was transferred to a 70 µm cell strainer and homogenized using a syringe plunger in 4 mL of PBS (containing 10% FBS) until completely filtered through the nylon mesh. The resulting cell suspension was centrifuged at 300g for 5 min, and the supernatant was discarded. To lyse red blood cells, 5 mL of 1x RBC lysis buffer was added and incubated at room temperature for 10 min. The suspension was then centrifuged again at 300g for 5 min, and the pellet was resuspended in 5 mL of sterile PBS containing 10% FBS. After a final centrifugation step, the pellet was resuspended in PBS containing 1% FBS, and the cell concentration was adjusted to 10^7 cells/mL for further use.
Instrument	Cytek NL-CLC3000
Software	Flowjo_V10.8.1
Cell population abundance	No sorting was performed.
Gating strategy	Gating was first based on FSC/SSC and singlet cells were gated for further analysis. The cell populations were then analyzed based on expression of markers. Gating was then based on positive levels. The detailed gating strategies are shown in Supplementary Fig. 18.

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