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	The particle size, size distribution, and zeta potential were measured using a Malvern DLS Zetasizer. The morphology of nanoparticles was acquired by transmission electron microscopy (Talos F200X S), scanning electron microscope (Scios2 Hivac) and Cryo-transmission electron microscopy (Talos F200C 200kV, FEI). Mass spectrometry was obtained on a Agilent 1290 Infinity II-6470. HRMS was obtained on a Ultraflextreme high-resolution mass spectrometer. NMR spectra were obtained on a Bruker Avance III 400MHz spectrometer. Flow cytometry data were obtained using a BD FACSAria III. The absorbance at 450 nm or 562 nm in 96 well plates were measured using a Synergy H1 microplate reader (BioTek). Quantitative PCR was performed on a StepOnePlus Real-time PCR System (Applied Biosystems). TEM images of cell samples were obtained using a Hitachi H-7650 TEM. Fluorescence microscopy images were acquired by Nikon AX R confocal microscope with 405-nm, 488-nm , 561-nm, and 639-nm lasers. Gels and blots were imaged using a Chemiluminescence Imaging System (SH-Cute 523, Shenhua Science Technology Co., Ltd., Shanghai). The images of wound healing assay and cell migration and invasion assay were obtained by a SOPTOP XD20 microscope. The concentration of extracellular vesicles was measured using a Nanocoulter G counter (Resuntech Co., Ltd., Shenzhen).
Data analysis	Graphpad Prism (v 8.0) was used for data analysis. FlowJo (v 10.0) was used for flow cytometry data analysis. Zetasizer Software was used for particle size analysis. MestRenova (v14.0.0) was used for NMR analysis.

Fiji was used for Western blot quantification.
NIS-Elements Viewer (v 5.21) was used for fluorescence microscopy image analysis.

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 relevant to the manuscript are included in the article and its Supplementary Information. Further details and information could be provided by the corresponding authors upon 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	No statistical methods were used to predetermine the sample size. Sample size was chosen based on previous lab experience to detect meaningful differences between treatments. There is low variability between western blot and flow cytometry experiments. Sample size followed common standard of n=2 or more biological replicates.
Data exclusions	There were no data exclusions except those resulting from technical errors making data interpretation impossible.
Replication	All experiments were successfully replicated with at least two biological replicates.
Randomization	The order of analysis for flow cytometry experiment was randomized. No other randomization was used as internal controls were used for quantitative comparisons.
Blinding	No blinding was performed in order to make comparisons between specific treatments.

Behavioural & social sciences study design

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

Study description	n/a

Research sample	n/a
Sampling strategy	n/a
Data collection	n/a
Timing	n/a
Data exclusions	n/a
Non-participation	n/a
Randomization	n/a

Ecological, evolutionary & environmental sciences study design

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

Study description	n/a
Research sample	n/a
Sampling strategy	n/a
Data collection	n/a
Timing and spatial scale	n/a
Data exclusions	n/a
Reproducibility	n/a
Randomization	n/a
Blinding	n/a

Did the study involve field work? ☐ Yes ☒ No

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

Goat Anti-Rabbit IgG Fc (Biotin), Abcam (ab97198), Functional;

Goat Anti-Mouse IgG H&L (Biotin), Abcam (ab207996), Functional;

Rabbit IgG, Elabscience (E-AB-1128), Functional;

Mouse IgG, Abmart (B30010M), Functional;

Rabbit IgG-Cy5, Shanghai Yaji Biological Co., Ltd (Ys-0295P-Cy5), Functional;

Anti-PDL1 antibody, Abcam (ab213480), Functional, WB, 1:1000;

Anti-PDL1 antibody, Proteintech (66248-1-Ig), IF, 1:200;

Anti-PDL1 antibody, BioXCell (BE0101), Functional;

FITC Anti-mouse CD274/PD-L1 Antibody, Elabscience (E-AB-F1132UC), Functional;

MMP-2 (D8N9Y) Rabbit mAb, Cell Signaling Technology (13132), WB, 1:1000;

Anti-MMP2 antibody, Abcam (ab92536), Functional, WB, 1:1000;

Biotin-Annexin V, Biolegend (640904), Functional;

Annexin V-Biotin Reagent, Elabscience (E-CK-A110), Functional;

Goat Anti-Mouse IgG H&L (Alexa Fluor® 647), Abcam (ab150115), IF, 1:1000;

Goat Anti-Rabbit IgG H&L (FITC conjugated), Elabscience (E-AB-1014), IF, 1:100;

EEA1 (C45B10) Rabbit mAb, Cell Signaling Technology (3288), WB, 1:1000;

Rab7 (D95F2)XP® Rabbit mAb, Cell Signaling Technology (9367), WB, 1:1000;

LAMP1 (D2D11)XP® Rabbit mAb, Cell Signaling Technology (9091), IF, 1:400;

CD107a / LAMP1 Monoclonal antibody, Proteintech (67300-1-Ig), WB, 1:5000;

Anti-GAPDH Recombinant Rabbit Monoclonal Antibody, HUABIO (ET1601-4), WB, 1:1000;

HRP-labeled Goat Anti-Rabbit IgG (H+L), Beyotime Biotechnology Co., Ltd (A0208), WB, 1:2000;

HRP-labeled Goat Anti-Mouse IgG (H+L), Beyotime Biotechnology Co., Ltd (A0216), WB, 1:2000.

Validation

All antibodies used were validated antibody suppliers per quality assurance as detailed on each supplier's website.

Goat Anti-Rabbit IgG Fc (Biotin)(ab97198, Abcam):https://www.abcam.cn/products/secondary-antibodies/goat-rabbit-igg-fc-biotin-ab97198.html. Validated from manufacturer's website and citations therein.

Goat Anti-Mouse IgG H&L (Biotin)(ab207996, Abcam):https://www.abcam.cn/products/secondary-antibodies/goat-mouse-igg-hl-biotin-ab207996.html. Validated from manufacturer's website and citations therein.

Rabbit IgG (E-AB-1128, Elabscience):https://www.elabscience.cn/p-rabbit_igg-573438.html. Validated from manufacturer's website.

Mouse IgG (B30010M, Abmart):http://www.ab-mart.com.cn/page.aspx?node=%2066%20&id=%201003. Validated from manufacturer's website and citations therein.

Rabbit IgG-Cy5 (Shanghai Yaji Biological Co., Ltd):http://www.yajimall.com/product/detail/38618.html. Validated from manufacturer's website.

Anti-PDL1 antibody (ab213480, Abcam):https://www.abcam.cn/products/primary-antibodies/pd-l1-antibody-epr20529-ab213480.html. Validated from manufacturer's website and citations therein.

Anti-PDL1 antibody (66248-1-Ig, Proteintech):https://www.ptgcn.com/products/PD-L1-CD274-Antibody-66248-1-Ig.htm. Validated from manufacturer's website and citations therein.

Anti-PDL1 antibody (BE0101, BioXCell):https://bioxcell.com/invivomab-anti-mouse-pd-l1-b7-h1-be0101. Validated from manufacturer's website and citations therein.

FITC Anti-mouse CD274/PD-L1 Antibody (E-AB-F1132UC, Elabscience):https://www.elabscience.com/p-fitc_anti_mouse_cd274_pd_l1_antibody_10f.9g2_-385724.html. Validated from manufacturer's website and citations therein.

MMP-2 (D8N9Y) Rabbit mAb (13132, Cell Signaling Technology):https://www.cellsignal.cn/products/primary-antibodies/mmp-2-d8n9y-rabbit-mab/13132. Validated from manufacturer's website and citations therein.

Anti-MMP2 antibody (ab92536, Abcam):https://www.abcam.cn/products/primary-antibodies/mmp2-antibody-epr1184-ab92536.html. Validated from manufacturer's website and citations therein.

Biotin-Annexin V (640904, Biolegend):https://www.biolegend.com/en-us/products/biotin-annexin-v-9787. Validated from manufacturer's website and citations therein.

Annexin V-Biotin Reagent (E-CK-A110, Elabscience):https://www.elabscience.cn/p-annexin_v_biotin_reagent-260151.html. Validated from manufacturer's website.

Goat Anti-Mouse IgG H&L (Alexa Fluor® 647) (ab150115, Abcam):https://www.abcam.cn/products/secondary-antibodies/goat-mouse-igg-hl-alexa-fluor-647-ab150115.html. Validated from manufacturer's website and citations therein.

Goat Anti-Rabbit IgG H&L (FITC conjugated) (E-AB-1014, Elabscience):https://www.elabscience.cn/p-goat_anti_rabbit_igg_h_l_fitc_conjugated_-77939.html. Validated from manufacturer's website.

EEA1 (C45B10) Rabbit mAb (3288, Cell Signaling Technology):https://www.cellsignal.cn/products/primary-antibodies/eea1-c45b10-rabbit-mab/3288. Validated from manufacturer's website and citations therein.

Rab7 (D95F2)XP® Rabbit mAb (9367, Cell Signaling Technology):https://www.cellsignal.cn/products/primary-antibodies/rab7-d95f2-xp-rabbit-mab/9367. Validated from manufacturer's website and citations therein.

LAMP1 (D2D11)XP® Rabbit mAb (9091, Cell Signaling Technology):https://www.cellsignal.cn/products/primary-antibodies/lamp1-d2d11-xp-rabbit-mab/9091. Validated from manufacturer's website and citations therein.

CD107a / LAMP1 Monoclonal antibody (67300-1-Ig, Proteintech):https://www.ptgcn.com/products/CD107a-Antibody-67300-1-Ig.htm. Validated from manufacturer's website and citations therein.

Anti-GAPDH Recombinant Rabbit Monoclonal Antibody (ET1601-4, HUABIO): http://www.huabio.cn/product/GAPDH-antibody-ET1601-4. Validated from manufacturer's website.

HRP-labeled Goat Anti-Rabbit IgG (H+L) (A0208, Beyotime Biotechnology Co., Ltd):https://www.beyotime.com/product/A0208.htm. Validated from manufacturer's website.

HRP-labeled Goat Anti-Mouse IgG (H+L) (A0216, Beyotime Biotechnology Co., Ltd):https://www.beyotime.com/product/A0216.htm. Validated from manufacturer's website.

Eukaryotic cell lines

Policy information about cell lines and Sex and Gender in Research

Cell line source(s)	B16F10, CT26, SKOV3, MCF-7, MDAMB231, 4T1, HeLa and HepG2 cell lines were obtained from the Cell Bank of the Chinese Academy of Sciences (Shanghai, China). Raw 264.7 cell was purchased from Procell Life Science&Technology Co., Ltd. (Wuhan, China). ECDHCC-1 cell was purchased from Fusheng Industrial Co., Ltd. (Shanghai, China).
Authentication	Cell lines have not been subjected to additional authentication.
Mycoplasma contamination	Cell lines were not tested for mycoplasma contamination.
Commonly misidentified lines (See ICLAC register)	No commonly misidentified cell lines were used.

Palaeontology and Archaeology

Specimen provenance	n/a
Specimen deposition	n/a
Dating methods	n/a

☐ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight	n/a

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

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	C57BL/6 mouse, 6-8 weeks old

Wild animals	n/a
Reporting on sex	Only female mice were used in the study.
Field-collected samples	n/a
Ethics oversight	All animal experiments were performed according to the protocols approved by the Institutional Animal Care and Use Committee (IACUC) of Zhejiang University (approval number: 20379) in accordance with the institutional guidelines.

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

Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration	n/a
Study protocol	n/a
Data collection	n/a
Outcomes	n/a

Dual use research of concern

Policy information about dual use research of concern

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes	
☒	☐	Public health
☒	☐	National security
☒	☐	Crops and/or livestock
☒	☐	Ecosystems
☒	☐	Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes	
☒	☐	Demonstrate how to render a vaccine ineffective
☒	☐	Confer resistance to therapeutically useful antibiotics or antiviral agents
☒	☐	Enhance the virulence of a pathogen or render a nonpathogen virulent
☒	☐	Increase transmissibility of a pathogen
☒	☐	Alter the host range of a pathogen
☒	☐	Enable evasion of diagnostic/detection modalities
☒	☐	Enable the weaponization of a biological agent or toxin
☒	☐	Any other potentially harmful combination of experiments and agents

Plants

Seed stocks: n/a

Novel plant genotypes: n/a

Authentication: n/a

ChIP-seq

Data deposition

☐ Confirm that both raw and final processed data have been deposited in a public database such as GEO.

☐ Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

Data access links
May remain private before publication.: n/a

Files in database submission: n/a

Genome browser session
(e.g. UCSC): n/a

Methodology

Replicates: n/a

Sequencing depth: n/a

Antibodies: n/a

Peak calling parameters: n/a

Data quality: n/a

Software: 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: For endocytosis experiments, the cells were washed twice with PBS after a certain period of incubation of the nanomaterials, trypsinized for <1 minute and transferred to Eppendorf tubes. The cells were washed twice with PBS + 0.5% FBS and resuspended in 200 µL of PBS. Flow cytometry was performed on a BD FACSAria III and gating was performed on single cells and live cells before acquisition of 10,000 cells. Analysis was performed using the FlowJo software.

Instrument: BD FACSAria III

Software: Data analysis was performed using the FlowJo v10.0.

Cell population abundance: N/A-cell sorting was not performed.

Gating strategy | Representative gating strategies are in the Supplementary Fig. 2. Debris was gated out by the FSC and SSC area, and single cells were gated on FSC-A and FSC-H, and live cells were gated.

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

Magnetic resonance imaging

Experimental design

Design type	n/a
Design specifications	n/a
Behavioral performance measures	n/a

Acquisition

Imaging type(s)	n/a
Field strength	n/a
Sequence & imaging parameters	n/a
Area of acquisition	n/a

Diffusion MRI ☐ Used ☒ Not used

Preprocessing

Preprocessing software	n/a
Normalization	n/a
Normalization template	n/a
Noise and artifact removal	n/a
Volume censoring	n/a

Statistical modeling & inference

Model type and settings	n/a
Effect(s) tested	n/a

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both

Statistic type for inference (See Eklund et al. 2016)	n/a
Correction	n/a

Models & analysis

n/a	Involved in the study
☒	☐ Functional and/or effective connectivity
☒	☐ Graph analysis
☒	☐ Multivariate modeling or predictive analysis