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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	No software was used
Data analysis	The pathological images were analyzed using Image J. Flow cytometry results were analyzed using FlowJo™ v. 10.0.7 software. The data from single-cell RNA sequencing and spatial transcriptomics were analyzed using the OmicStudio tools developed by LC-BIO Co., Ltd. (Hangzhou, China) at https://www.omicstudio.cn/cell.

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 the data are available in the main text or the supplementary materials. The sc-RNA seq data and spatial transcriptomic data that support the findings of this study are openly available in the Genome Sequence Archive at https://ngdc.cncb.ac.cn/gsa/s/Jcm71pYO, reference number CRA027691.

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	NA
Reporting on race, ethnicity, or other socially relevant groupings	NA
Population characteristics	NA
Recruitment	NA
Ethics oversight	NA

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	Total 63 MRL/lpr mice (LN, lupus nephritis model) and 51 female MRL/MPJ mice (Con, LN control model) were utilized in this study.
Data exclusions	We excluded from the analysis animals, which did not present signs on lupus nephritis (The concentration of autoantibodies in the serum).
Replication	Biological duplications are clearly illustrated in the figure, The raw statistical datas were provided in the supplementary data file.
Randomization	Random number table was used for experimental grouping.
Blinding	All animals received equal care, and animal caregivers were blinded.

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

1: Mouse anti-dsDNA ELISA Kit (supplier name: Alpha Diagnostic Intl, catalog number: 5120, lot number: 240822K4)
2: Mouse ANA ELISA Kit (supplier name: Alpha Diagnostic Intl, catalog number: 5210, lot number: 240822K5)
3: Anti-CD45 antibody (supplier name: abcam, catalog number: ab10558, clone name: Rabbit polyclonal, lot number: 1072771-1)
4: Anti-CD68 antibody (supplier name: abcam, catalog number: ab283654, clone name: EPR23917-164, lot number: 1008461-36)

5: Anti-CD138 antibody (supplier name: abcam, catalog number: ab128936, clone name: EPR6454, lot number: 1068804-2)
6: CXCL4 (supplier name: RayBiotech, catalog number: EML-PF4-1, lot number: 0617248026)
7: CXCL9 (supplier name: RayBiotech, catalog number: EML-MIG-1, lot number: 0812240485)
8: CXCL10 (supplier name: RayBiotech, catalog number: EML-CRG2-1, lot number: 0401240568)
9: CXCL11 (supplier name: RayBiotech, catalog number: EML-ITAC-1, lot number: 0308240510)
10: CXCL12 (supplier name: RayBiotech, catalog number: ELM-SDF1a-1, lot number: 032724232)
11: CXCL13 (supplier name: RayBiotech, catalog number: ELM-BLC-1, lot number: 0408248010)
12: CCL19 (supplier name: RayBiotech, catalog number: ELM-MIP3b-1, lot number: 0617247043)
13: CCL21 (supplier name: RayBiotech, catalog number: ELM-6Ckine-1, lot number: 0617242001)
14: PE/Dazzle™ 594 anti-mouse CD45 Antibody (supplier name: BioLegend, catalog number: 103146, clone name: 30-F11, lot number: B407721)
15: Brilliant Violet 421™ anti-mouse CD138 (Syndecan-1) Antibody (BioLegend, catalog number: 142523, clone name: 281-2, lot number: B387829)
16: APC anti-mouse/human CD45R/B220 Antibody (BioLegend, catalog number: 103121, clone name: RA3-6B2, lot number: B379792)
17: FITC anti-BrdU Antibody (BioLegend, catalog number: 364104, clone name: 3D4, lot number: B377768)
18: FITC anti-mouse CD45 Antibody (BioLegend, catalog number: 103108, clone name: 30-F11, lot number: B399569)
19: PerCP/Cyanine5.5 anti-mouse/human CD11b Antibody (BioLegend, catalog number: 101227, clone name: M1/70, lot number: B375903)
20: Brilliant Violet 421™ anti-mouse F4/80 Antibody (BioLegend, catalog number: 123137, clone name: BM8, lot number: B402385)
21: PE anti-mouse CXCL9 (MIG) Antibody (BioLegend, catalog number: 515604, clone name: MIG-2F5.5, lot number: B413041)
22: Brilliant Violet 650™ anti-mouse CD183 (CXCR3) Antibody (BioLegend, catalog number: 124531, clone name: CXCR3-173, lot number: B379381)

Validation

1: Mouse anti-dsDNA ELISA Kit (https://www.4adi.com/4adi/mouse-anti-dsdna-igg-specific-elisa-kit-96-tests-quantitative-9756-p.html)
2: Mouse ANA ELISA Kit (https://www.4adi.com/4adi/mouse-anti-nuclear-antigens-ana-ena-ig-s-total-a-g-m-elisa-kit-96-tests-quantitative-9759-p.html)
3: Anti-CD45 antibody (https://www.abcam.cn/products/primary-antibodies/cd45-antibody-ab10558.html)
4: Anti-CD68 antibody (https://www.abcam.cn/products/primary-antibodies/cd68-antibody-epr23917-164-ab283654.html)
5: Anti-CD138 antibody (https://www.abcam.cn/products/primary-antibodies/syndecan-1-antibody-epr6454-ab128936.html)
6: Mouse anti-CXCL4 ELISA Kit (https://www.raybiotech.com/mouse-pf-4-elisa-elm-pf4)
7: Mouse anti-CXCL9 ELISA Kit (https://www.raybiotech.com/mouse-mig-elisa-elm-mig)
8: Mouse anti-CXCL10 ELISA Kit (https://www.raybiotech.com/mouse-crg-2-elisa-elm-crg2)
9: Mouse anti-CXCL11 ELISA Kit (https://www.raybiotech.com/mouse-i-tac-elisa-elm-itac)
10: Mouse anti-CXCL12 ELISA Kit (https://www.raybiotech.com/mouse-sdf-1-alpha-elisa-elm-sdf1a)
11: Mouse anti-CXCL13 ELISA Kit (https://www.raybiotech.com/mouse-blc-elisa-elm-blc)
12: Mouse anti-CCL19 ELISA Kit (https://www.raybiotech.com/mouse-mip-3-beta-elisa-elm-mip3b)
13: Mouse anti-CCL21 ELISA Kit (https://www.raybiotech.com/mouse-6ckine-elisa-elm-6ckine)
14: PE/Dazzle™ 594 anti-mouse CD45 Antibody (https://www.biolegend.com/en-us/products/pe-dazzle-594-anti-mouse-cd45-antibody-10070)
15: Brilliant Violet 421™ anti-mouse CD138 (Syndecan-1) Antibody (https://www.biolegend.com/en-us/products/brilliant-violet-421-anti-mouse-cd138-syndecan-1-antibody-7852)
16: APC anti-mouse/human CD45R/B220 Antibody (https://www.biolegend.com/en-us/products/apc-anti-mouse-human-cd45r-b220-antibody-442)
17: FITC anti-BrdU Antibody (https://www.biolegend.com/en-us/products/fitc-anti-brdu-antibody-10623)
18: FITC anti-mouse CD45 Antibody (https://www.biolegend.com/en-us/products/fitc-anti-mouse-cd45-antibody-99)
19: PerCP/Cyanine5.5 anti-mouse/human CD11b Antibody (https://www.biolegend.com/en-us/products/percp-cyanine5-5-anti-mouse-human-cd11b-antibody-4257)
20: Brilliant Violet 421™ anti-mouse F4/80 Antibody (https://www.biolegend.com/en-us/products/brilliant-violet-421-anti-mouse-f4-80-antibody-7199)
21: PE anti-mouse CXCL9 (MIG) Antibody (https://www.biolegend.com/en-us/products/pe-anti-mouse-cxcl9-mig-antibody-6147)
22: Brilliant Violet 650™ anti-mouse CD183 (CXCR3) Antibody (https://www.biolegend.com/en-us/products/brilliant-violet-650-anti-mouse-cd183-cxcr3-antibody-9384)

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	MRL/lpr and MRL/MPJ mice
Wild animals	The study did not involve wild animals
Reporting on sex	Only female mice were used in this experiment because 80% of patients with lupus nephritis are female
Field-collected samples	All mice were kept in specific pathogen-free facilities and housed with 12 h cycles of light/darkness and a standard chow diet at 25 °C. The mice were euthanized at various time points: 4 weeks , 8 weeks, 12 weeks, 16 weeks, 20 weeks, and 24 weeks.
Ethics oversight	We have complied with all relevant ethical regulations for animal use. Animal experiments were performed in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and approved by the Institutional Animal Care and Use Committee of the Chinese PLA General Hospital (No. 2023-X19-24).

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

Plants

Seed stocks	NA
Novel plant genotypes	NA
Authentication	NA

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	Freshly surgically resected kidney samples (4w LN, 12w LN, 20w LN) were first minced and enzymatically digested (1 ml of 0.25 mg/mL LiberaseTM (Roche, #5401119001) + 100 µL of 100 U/mL Dnase I (Solarbio, #D8071)) in a 37 ? laboratory water bath for 30 minutes to obtain tissue lysis solution. Subsequently, the tissue lysis solution will be filtered through 100um and 40um cell filters respectively to obtain single-cell suspensions. Collect 100µL peripheral blood samples from mice and store them in anticoagulant tubes. The peripheral blood and single-cell suspensions of kidney were prepared and stained successively with the Zombie Aqua™ viability dye (BioLegend, #423101), cell-surface antibodies, Foxp3/Transcription Factor Staining Buffer Set (eBioscience, #00-5523-00), and intracellular antibodies.
Instrument	Data were acquired using a Beckman DXFLEX cytometer.
Software	Analysis was conducted with BD FlowJo™ v. 10.0.7 software.
Cell population abundance	Single cell RNA sequencing CD45+ and CD45- live cells were sorted using a Cytek Aurora cell sorter. FITC anti-mouse CD45 Antibody (BioLegend, catalog number: 103108, clone name: 30-F11, lot number: B399569) was utilized. The CD45+ immune cells and CD45- cells were then mixed in a ratio of 4:1 and pooled together. The purity of each cell type reached 90%. The proportion of cell types in the single-cell RNA equencing data can be confirmed. The data are listed in the Table. S3 .
Gating strategy	First, select FSC-A for the x-axis and SSC-A for the y-axis. Encircle the majority of the cells while removing debris and impurities at the edges. Second, select FSC-A for the x-axis and FSC-H for the y-axis. Encircle individual cells and eliminate any clumped cells. Third, select Live/Dead BV510-H for the x-axis and SSC-A for the y-axis, and encircle the live cells. Forth, select CD45 ECD-A for the x-axis and SSC-A for the y-axis, and encircle the CD45+ lymphocytes. Fifth, among the CD45+ cells, select CD138 BV421-A for the x-axis and B220 APC-H for the y-axis. Encircle the CD138+/B220+ and CD138+/B220- cell populations. Sixth, after selecting the CD138+/B220+ and CD138+/B220- cell populations, choose BrdU FITC-H for the x-axis and SSC-A for the y-axis, and encircle the Trans PC4, PC1, and PC2 cell populations. After selecting TransPC4, choose CD183 Violet660-H for the x-axis and SSC-H for the y-axis, then circle the CXCR3+ TransPC4 cell population. Seventh, in the CD45+ cell population, select CD11bPC5.5-A for the x-axis and F4/80 BV421-A for the y-axis. After selecting the double-positive cells, choose CXCL9 PE-A for the x-axis and SSC-A for the y-axis, then circle the CXCL9+ macrophages among the macrophages.The positive threshold for each fluorescent marker is established based on FMO and blank control, considering the fluorescence intensity of each marker and the variations between groups. A detailed flowchart is included in the supplementary materials (Figure S3, Figure S6, Figure S7, Figure S8).

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